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An analysis of the Tactical Unmanned Vehicle during Amphibious Assault Combat Operations using the JCATS combat model

America, John F.

Monterey, California. Naval Postgraduate School

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THESIS

AN ANALYSIS OF THE TACTICAL UNMANNED VEHICLE DURING AMPHIBIOUS ASSAULT COMBAT OPERATIONS USING THE JCATS COMBAT MODEL

by

John F. America

June 1999

Thesis Advisor:	Bard K. Mansager
Second Reader:	Maurice D. Weir

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The Unmanned Ground Vehicle/System Joint Project Office is currently developing a family of unmanned ground systems that may have the potential to give the ground combat commander the ability to gain a decisive advantage in the battle for information dominance. By harnessing the power of robotics in a reconnaissance, surveillance and target acquisition role, the UGV is designed to provide the maneuver battalion commander with the ability to extend his influence beyond the capabilities of traditional scouts.

This thesis examined the Unmanned Ground Vehicle Medium (UGVM) using the Joint Conflict and Tactical Simulation (JCATS) model to evaluate the impact of changes to performance characteristics of the system. The scenario used for the simulation was based on Exercise KERNEL BLITZ (KB), a biennial joint amphibious operation conducted on the West Coast of the United States.

The UGVM's communication limitations and speed were varied in the JCATS simulations. Measures of effectiveness (MOEs) for these changes included total blue detections, blue detections over time, total blue kills, and blue losses over time.

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John F. America
Captain, United States Marine Corps
B.B.A., University of Oklahoma, 1992

Submitted in partial fulfillment of the
requirements for the degree of

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June 1999

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ABSTRACT

The Unmanned Ground Vehicle/System Joint Project Office is currently developing a family of unmanned ground systems that may have the potential to give the ground combat commander the ability to gain a decisive advantage in the battle for information dominance. By harnessing the power of robotics in a reconnaissance, surveillance and target acquisition role, the UGV is designed to provide the maneuver battalion commander with the ability to extend his influence beyond the capabilities of traditional scouts.

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LIST OF SYMBOLS, ACRONYMS, AND/OR ABBREVIATIONS

α	Level of Significance
μ	Mean
ν	Adjusted Degrees of Freedom
σ^2	Variance
S_p	Pooled Estimate of Variance
TS	Test Statistic
W	Wilcoxon Statistic
X	Random Variable X
Y	Random Variable Y
2-69	2nd Battallion, 69th Armor Brigade
AAV	Assault Amphibious Vehicle
ANOVA	Analysis of Variance
AWS	Analyst Workstation
CAAT	Combined Arms Anti-tank
CDF	Cumulative Distribution Function
CS	Control Station
DoD	Department of Defense
E 2/5	Echo Company, 2nd Battallion, 5th Marines
G 2/5	Golf Company, 2nd Battalion, 5th Marines
JCATS	Joint Conflict and Tactical Simulation
JPO	Joint Project Office
KS	Kolmogorov-Smirnov

LAV	Light Armored Vehicle
LOS	Line of Sight
MEU	Marine Expeditionary Unit
MOE	Measure of Effectiveness
NPS	Naval Postgraduate School
NVEOL	Night Vision Electro-optical Laboratory
ORD	Operational Requirements Document
PP	Payload Platform
RF	Radio Frequency
RSTA	Reconnaissance, Surveillance, and Target Acquisition
SARGE	Surveillance and Reconnaissance Ground Equipment
SP	Sensor Package
TUVM	Tactical Unmanned Vehicle Medium
UGV/S	Unmanned Ground Vehicle/Systems
WMD	Weapon of Mass Destruction

EXECUTIVE SUMMARY

The Unmanned Ground Vehicle/System Joint Project Office is currently developing a family of unmanned ground systems that may give the ground combat commander a decisive advantage in the battle for information dominance. By harnessing the power of robotics in a reconnaissance, surveillance and target acquisition role, the UGV is designed to provide the maneuver battalion commander with the ability to extend his influence beyond the capabilities of traditional scouts. The UGV has the potential to increase the lethality of a force while significantly reducing the risk to scout personnel.

This thesis examined the Unmanned Ground Vehicle Medium (UGVM) using the Joint Conflict and Tactical Simulation (JCATS) model to evaluate the impact of changes to performance characteristics of the system. The scenario used for the simulation was based on Exercise KERNEL BLITZ (KB), a biennial joint amphibious operation conducted on the West Coast of the United States.

The operational premise for KB has a notional Third-world country, Orange, attempting to establish political and military dominance in its region, the West Coast of the United States. Orange has supported violent insurgencies in regional nations friendly to the United States, especially country Green. Recent humanitarian disasters prompted the introduction of American military forces into country Green. Orange's intensified military activity, increasing support of the insurgents, and threats to vital sea lanes in the area dictate a military response from the United States. The notional island of San Pendleton (Marine Corps Base Camp Pendleton) is seized to support the invasion of the mainland near San Diego.

Within this operational framework, the activity of 2nd Battalion, 5th Marines Regiment was modeled. UGVMs were then inserted into the scenarios. The UGVM's communication limitations and speed were varied in the JCATS simulations. Measures of effectiveness (MOEs) for these changes included total blue detections, blue detections over time, total blue kills, and blue losses over time.

The analysis of the results indicates statistically significant differences between the cases. The UGVM equipped forces consistently suffered fewer casualties and killed more red forces than non-UGVM scenarios. Unexpectedly, the number of acquisitions reported for the blue force decreased when using the UGVM, indicating a need for more detailed analysis of the relationship between acquisitions and kill events.

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I. INTRODUCTION

A. OVERVIEW

1. Advances in Information Warfare

Fundamental changes in military decision-making capabilities are potentially the most dramatic result of the rapid advancement in military technology. The decision cycle (observe, orient, decide, act) has been compressed with advances in communications and command and control systems. Whichever force can make and implement its decision consistently faster than the opponent gains a tremendous and often decisive advantage on the battlefield. [Ref. 1] The battle to rapidly gain information superiority has become increasingly important as the decision cycle is compressed. By coupling the power of robotics with information systems, tactical unmanned systems may be able to reduce significantly the uncertainty and ambiguity that permeate military operations and enable the commander to win the information war.

2. Scope of Thesis

The Unmanned Ground Vehicle/Systems Joint Project Office (UGV/S JPO) is the U.S. Army's and U.S. Marine Corps' acquisition proponent for unmanned ground systems. The UGV/S JPO is currently developing a family of UGVs for the battlefield of the future. Within this family is the Tactical Unmanned Vehicle (TUV), a teleoperated vehicle with a small but highly mobile platform designed to perform unmanned reconnaissance, surveillance, and target acquisition (RSTA) at the battalion level and below. One TUV prototype, a surveillance and reconnaissance system, has recently participated in several user appraisals. An early proponent of the TUV, the U.S. Army

Infantry School (USAIS), has recently focused on a smaller, man-packable system called the TUV light. The TUV prototype is now considered a TUV medium (TUVM). [Ref. 2]

The UGV/S JPO is studying the results of user appraisals and assessing the TUVM contribution to force effectiveness and researching key performance parameters for the TUVM for potential input into an update of the Operational Requirements Document (ORD). [Ref. 2] Potential improvements in TUVM performance and the associated increases in system complexity and cost must be evaluated against the potential benefit for the battlefield commander. This thesis examines potential changes to various performance parameters for TUVMs in an amphibious assault scenario using the Joint Conflict and Tactical Simulation (JCATS) Combat Simulation Model to simulate a portion of Exercise KERNEL BLITZ (KB).

B. BACKGROUND

1. TUVM Description

The TUVM is a system that includes an unmanned, remotely operated vehicle designed to provide maneuver forces (battalion and below) with an organic system capable of conducting RSTA. The TUVM attempts to enable the maneuver commander to conduct RSTA missions with fewer personnel resources, greater accuracy, greater distances, increased duration, and increased responsiveness. The TUVM consists of three major components.

a. Control Station (CS)

The CS allows the operator to remotely control all functions of the TUVM system. The CS is operated from a modified High Mobility Multi-Purpose Wheeled Vehicle (HMMWV).

b. Payload Platform (PP)

The Payload Platform provides mobility to deploy sensor packages. The PP is teleoperated from the CS.

c. Sensor Packages (SPs)

The SPs are the payloads that the PP will deliver to the battlefield. For this thesis, the only SP considered is the RSTA SP, which includes visual, infrared, and acoustic sensors. The SPs are controlled from the CS.

2. ORD System Performance Specifications

The following performance specifications are a partial listing of the ORD requirements for the TUVM:

TUVM System:

- Be capable of being transported on a HMMWV.
- Be capable of external air transport by UH-60, CH-47, CH-53 and V-22 aircraft.
- Be capable of internal air transport by CH-47 and CH-53 aircraft.
- Be Low Velocity Airdrop and Low Altitude Parachute Extraction System deliverable.
- Be one man operable in all battlefield conditions.
- Be placed to/from stowed transport position in 30 minutes or less.
- Conduct 24-hour RSTA missions without refuel, including up to 6 legs of 4 kilometers (km) each and up to 18 hours of continuous stationary, and 6 hours of continuous moving, operations.

Control Station:

- Be capable of remotely operating and controlling the SP and PP out to a distance of not less than 4 km RF/LOS.
- Be aurally non-detectable by the unaided ear beyond 100 meters.
- Be visually non-detectable by the unaided eye beyond 200 meters at night.

Payload Platform:

- Be capable of reaching and sustaining 25 kilometers per hour (kph) for not less than 25 minutes over flat paved surfaces.
- Be capable of maintaining 5 kph during cross-country movement.
- Be able to ford 30 centimeters (cm) of water.
- Climb a vertical step of 25 cm at a speed of 5 kph.
- Operate on 30 % side-slopes and 60 % front-slopes.
- Be aurally non-detectable while moving at 5 kph by the unaided ear beyond 300 meters.

Sensor Package:

- Permit 360 degree RSTA while in stationary mode.
- Permit operator detection of tank-sized vehicles at 4000 meters or personnel sized targets at 1000 meters, day or night, with a 90% probability on a day with 9 km of visibility (9 km day).
- Acoustically detect a moving (10 kph) tank at a distance of at least 1000 meters from the SP.

- Provide location (within 20 meters), range direction, and vertical angle of stationary tank-sized targets within 2000 meters, day or night, with a 90 % probability on a 9 km day.

These performance specifications were used to determine the attributes of the TUVM system created in the JCATS simulation used in this study. Additionally, some otherwise undirected attributes were based on the physical characteristics of the user appraisal prototype system described below. [Ref. 3]

3. User Appraisal Results

From November 1996 to April 1997, the U.S. Army's 2nd Battalion, 69th Armor Brigade (2-69 Armor) conducted the first in a series of planned user appraisals for a prototype TUVM, called the Surveillance and Reconnaissance Ground Equipment (SARGE). Four SARGE systems were sent to Scout Platoon, 2-69 Armor, which then tested the systems at Fort Benning, Georgia and the Marine Air Ground Combat Center (MAGCC), Twenty-nine Palms, California. The first user appraisal resulted in a resounding endorsement from the using unit of both the TUVM and the concept of unmanned reconnaissance and remote warfare. The SARGE-enabled the scout platoon to extend the range of their reconnaissance efforts without additional support from the platoon's parent battalion. SARGE-equipped scouts were able to detect targets earlier and engage them more effectively with indirect fires. Finally, TUVM-equipped scouts were able to remain in protected positions and survive longer. The user appraisal demonstrated the capability of the TUVM-equipped scout platoon to increase the operational effectiveness of 2-69 Armor. Additionally, the first user appraisal resulted in more than forty changes to the SARGE system. [Ref. 2]

C. JCATS COMBAT MODEL

Used throughout the Department of Defense (DoD) and other U.S. government agencies, JCATS was developed by Lawrence Livermore National Laboratory for combat and conflict training, exercises, analysis, experiments, and rehearsals. It evolved from a merger of the Joint Tactical Simulation (JTS) and the Joint Conflict Model (JCM). JCATS is a multi-sided, high resolution, entity level, combat simulation model. JCATS can model strategic through tactical levels across the broad spectrum of war, from Joint Task Force head-to-head engagements to individual conflicts in Operations-Other-Than-War.

The high resolution nature of JCATS allows the user or analyst to control the inputs and actions for individual systems in a scenario. The model also allows forces to be aggregated, or combined, into units or combat organizations for easier control. The user directs movement and activities of the systems and units under his control through the model environment with pre-planned or real-time routes.

Combat between systems or units in JCATS is based primarily on line of sight (LOS). Terrain and visibility parameters are checked by the JCATS acquisitions algorithm to determine whether a detection occurs. Once a system or unit has been detected, other algorithms and settings determine the weapon and munitions, if any, selected for use in an engagement and whether damage was inflicted.

The environment for the model consists of a terrain file representing the Marine Corps Base, Camp Pendleton, California area. This terrain file was created from elevation data obtained from the National Imagery and Mapping Agency (formerly the Defense Mapping Agency) in the form of DTED terrain data. The DTED terrain in this

study uses 100 meter resolution elevation data. Water features, vegetation, and all man-made objects were added by the author using standard military maps of the area.

Some of the most important features and capabilities of JCATS include:

- Amphibious landings and submarine play
- Platforms blocking LOS
- Four levels of acquisition
- Peripheral acquisitions
- Detailed trafficability model
- Multi-story urban operations with windows, doors and interior direct fire engagements with solid object interaction from buildings
- Precision guided weapons with supporting laser spotting
- FO to direct support asset automatic call for fire
- Detailed rules of engagement (ROE) settings
- Dynamically controlled non-homogeneous aggregation/disaggregation and mount/dismount functions
- Detailed human factors including fatigue, secondary suppression and fratricide

These JCATS features, paired with appropriate technical data and tactical inputs, can be combined to simulate some of the experiments required for new equipment like the TUVM. [Ref. 4]

D. OBJECTIVES

User appraisals and previous modeling and simulation efforts have explored the utility of TUV systems in many traditional ground combat environments with standard U.S. Army units and missions. Using a large-scale U.S. Marine Corps and Navy

amphibious exercise as the operational framework for the model, the JCATS simulations in this study attempt to capture the unique features of amphibious combat operations and emerging technologies for littoral combat in the next century.

The objective of this thesis is to examine the impact of changes in performance characteristics of the TUVM on the combat effectiveness of these systems. Using the ORD minimum requirements system as the baseline, the characteristics of speed, survivability and communications ability will be considered. Interaction between the performance characteristics is expected. As the simulations are conducted, a preliminary analysis may indicate the need to reduce the number of independent characteristics that require a full examination. Future research to gain additional insight into the tactical employment of UGV/S in amphibious operations may be based on the results of this thesis.

II. MODEL DESCRIPTION

A. BACKGROUND

1. Fleet Battle Experiment Echo (FBE-Echo)/KB

The future of naval warfare is being shaped in the Fleet Battle Experiments. The overriding purpose of these experiments is to test innovative concepts and technologies in a real-time battle scenario. In particular, FBE-Echo tested the future capabilities in both asymmetrical and traditional maritime environments. [Ref. 5] FBE-Echo was conducted in conjunction with KB, an umbrella exercise for a series of naval force operational events during 1999 on the West Coast of the United States. KB "Prime" is a traditional large-scale amphibious assault exercise, which will exercise a real-world contingency plan. For purposes of this thesis, the actual amphibious assault portion of KB will be referred to as KB-99. The analysis conducted in this thesis will use the first phase of the tactical operations during KB-99 of one of the U.S. Marine infantry battalions, 2nd Battalion, 5th Marine Infantry Regiment (2/5), as the tactical framework for the simulated scenarios. [Ref. 5]

2. KB-99 Political and Military Background Details

The KB-99 scenario is based on U.S. military forces conducting littoral operations against a generic third world country, Orange, and Orange supported rebels in country Green. These countries are located on the southwestern coast of the United States. The country of Orange consists of southern California, Arizona, and Nevada. Green consists of northern California. The scenario's geopolitical situation is intended to be representative of one which could occur in 1999 in a sensitive region, with hostilities eventually spanning low-to-mid-intensity conflict.

Orange is a religious oligarchy, generally hostile towards Western governments and views Western society as corrupt and immoral. Orange has supported insurgency movements in Green that support reunification with Orange. These movements include groups that use violence and terrorism in country Green. Orange views U.S. military operations in the area as a challenge to its own goal of regional hegemony. Green has been democratic since its inception. It has established good relations with the Western powers and is a strong supporter of U.S. activity in the region.

Militarily, Orange has the capacity to secure regional hegemony if unchecked. This will threaten U.S. vital interests in oilfields, exports, and manufacturing sites nearby. Neighboring countries posses the technology for inter-continental ballistic missiles (ICBM), which if captured by Orange, will have a devastating effect on the regional balance of power and U.S. economic interests. Orange's current missile and mining capabilities allow them to threaten sea lanes. Intelligence estimates indicate that Orange has chemical and biological warfare capabilities. Their ongoing development of these capabilities has bolstered their recent actions.

3. Current Military Situation

Recent Orange naval operations in the Straits of Barbara increased tensions and a forward deployed Amphibious Ready Group/Marine Expeditionary Unit (MEU) and Carrier Battle Group was ordered to the region. Orange insurgents intensified activity. The Green capital, Francisco City, was hit by a major earthquake and insurgents seized opportunity to interfere with commercial shipping in Francisco Bay. Green requested U.S. assistance, and U.S. Forces began humanitarian and peace operations in support of Green in Francisco Bay area. Orange retaliated by attacks on military and civilian

shipping off the coast of Southern California. U.S. military forces were tasked to open sea lanes and neutralize Orange's ability to militarily influence neighboring nations and threaten U.S. interests in the region. U.S. air and sea offensive began against Orange missile sites, weapons of mass destruction (WMD) facilities, and mine facilities. By April 10th, strategic and operational naval fires commenced against Orange armored forces, airfields, logistics bases, and command and control sites. Preparation has begun for the seizure of San Pendleton Island (a notional island consisting primarily of Camp Pendleton, separated from the mainland by approximately 10 miles) to facilitate the introduction of follow on forces. (Figure 1) [Ref. 5]

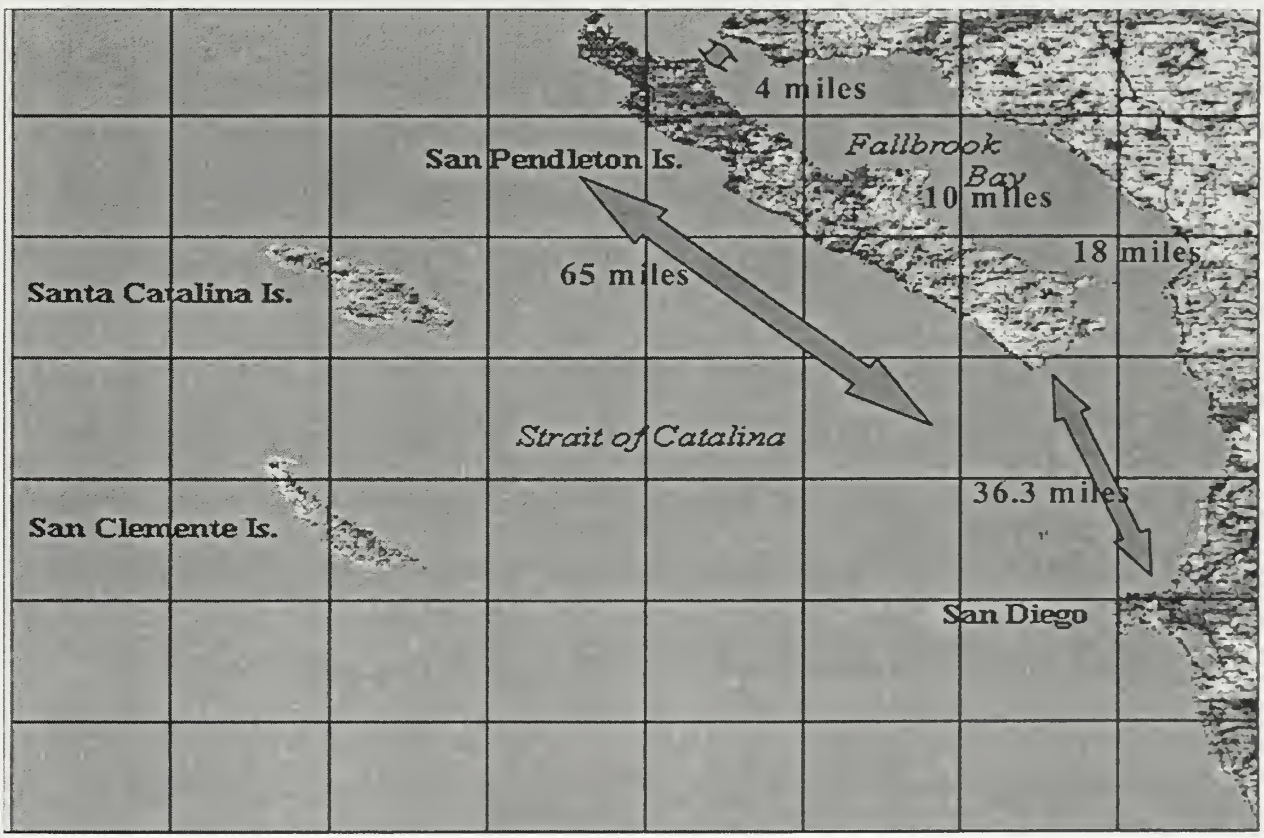

Figure 1. San Pendleton Island. From Ref. 6.

4. Amphibious Assault Plan

Regimental landing Team One (RLT-1) consists primarily of three infantry battalions, a tank company, artillery battery and supporting units. The RLT-1 is assigned the mission of seizing RLT OBJ A, neutralizing enemy forces, and securing cross channel sites in order to facilitate the rapid introduction of follow on forces. RLT-1's plan includes a surface assault in Assault Amphibious Vehicles (AAVs) by 2/5, a helicopter assault by 1st Battalion, 7th Marine Infantry Regiment (1/7) and landings of the remaining forces by landing craft.

5. 2/5 Scheme of Maneuver

The combat scenario in this thesis is generally based on the actual exercise operations order of 2/5, its attachments, and the combat activity closely tied to 2/5's maneuver during KB-99 through the first phase of the operation.

The operations by 2/5 were preceded by the landing of a platoon of Light Armored Vehicles (LAVs) via Landing Craft Air-Cushioned (LCAC) with the battalion reconnaissance teams. The LAVs secure Red Beach, so the beach area is considered clear of enemy forces. At H-Hour (7:00 a.m.), Golf Company 2/5 (G 2/5), is to land across Red Beach and move to an assembly area near the entrance to Las Pulgas Canyon. Echo Company 2/5 (E 2/5) then moves immediately to clear the high ground west of Las Pulgas Canyon, generally along Piedra de Lumbra Canyon.

Once this high ground is cleared, G 2/5 clears Las Pulgas Canyon and establishes a support by fire position southeast of RLT Objective A. E 2/5 then attacks to seize RLT Objective A. G 2/5 and the remaining battalion elements consolidate near the objective and prepare for the next phase. (Figure 2)

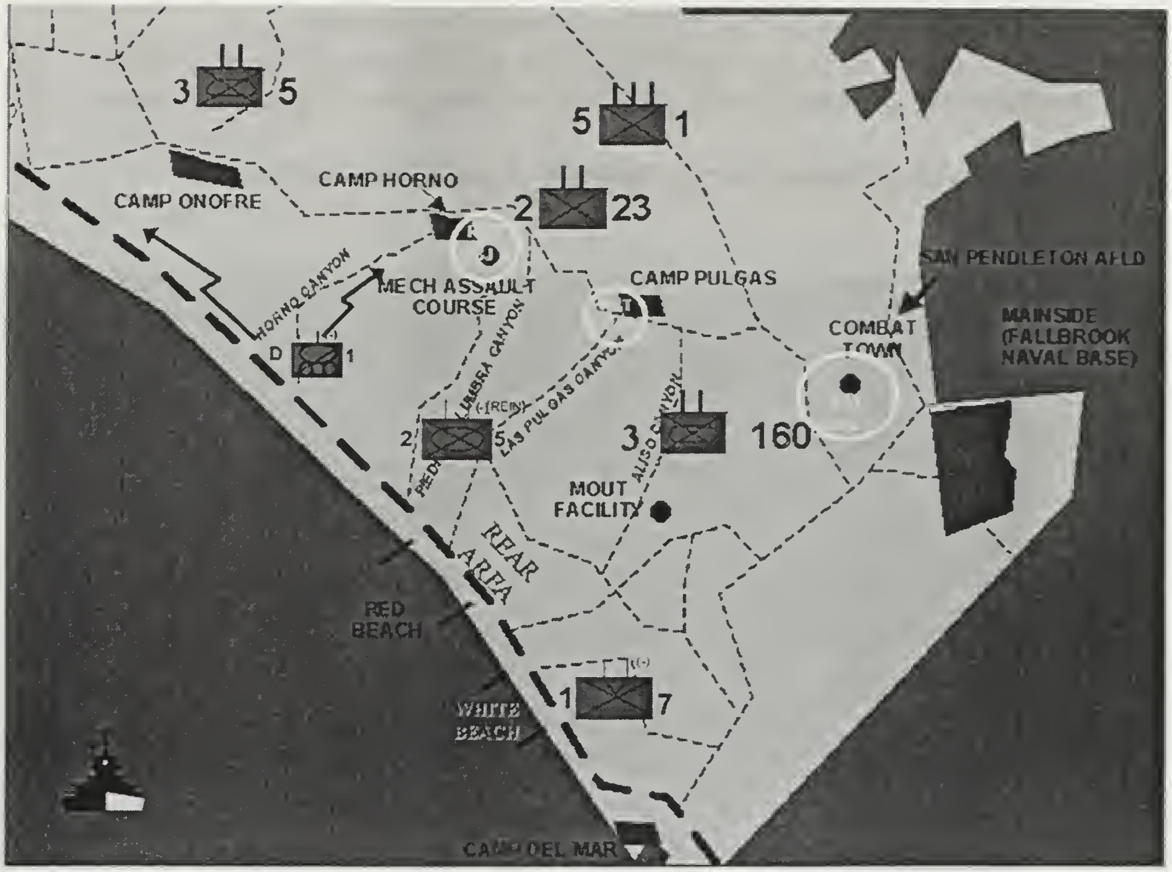

Figure 2. KB-99 Amphibious Assault. From Ref. 6.

Key terrain features and checkpoints are illustrated in Figure 3. The following is a brief description of the primary activities of each unit in the scenario:

G 2/5:

- Become main effort.
- At H-hour, Conduct amphibious assault across Red Beach and destroy enemy near RLT objective A.
- Establish assembly area near checkpoint 73.
- Become supporting effort.
- On order, clear Las Pulgas Canyon.

- Establish support by fire (SBF) position near checkpoint 9.
- On Order, establish a battle position near checkpoint 81A, oriented west-northwest to prevent enemy penetration from Horno Canyon.

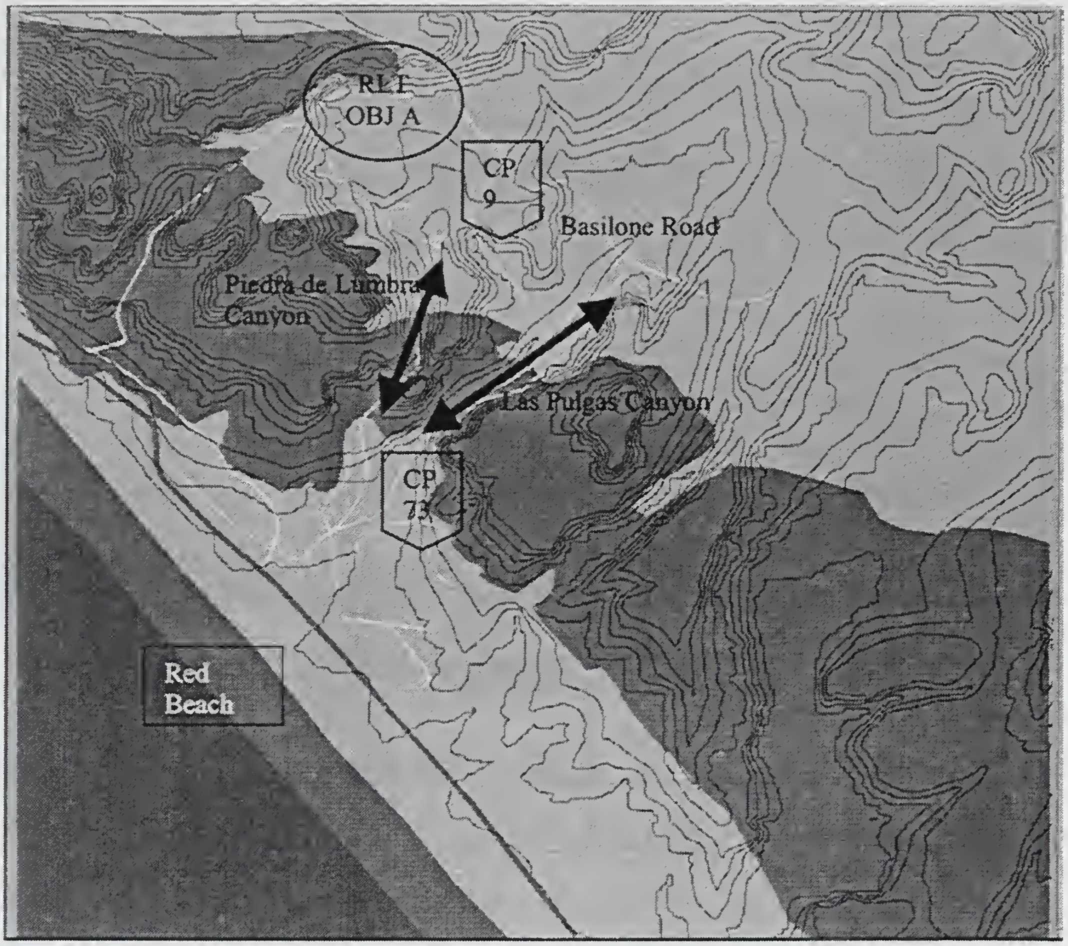

Figure 3. Key Terrain Features and Checkpoints.

E 2/5:

- Become supporting effort.
- At H-hour, conduct an amphibious assault across Red Beach, following in trace of G Company, and move immediately to checkpoint 10.

- On order, clear the high ground west flank of Las Pulgas Canyon in order to prevent enemy interference with the main effort's movement up Las Pulgas Canyon.
- On order, become the main effort.
- Attack enemy near RLT objective A in order to prevent enemy movement along Basilone Road.
- On order, consolidate near RLT objective A, protecting the right flank of the battalion position.

81mm Mortar Platoon:

- At H-hour, land on Red Beach.
- Follow in trace of E Company and establish firing positions to support maneuver elements.
- Displace by section to provide fires in support of attack on RLT objective A.
- On order, displace to near RLT objective A and provide fires in support of consolidation.
- Establish initial firing positions near grid 592855.
- Establish second firing positions near grid 591899.

Combined Arms Anti-tank (CAAT) Platoon:

- At H-hour, land on Red Beach and follow in trace of E Company to checkpoint 10.
- Provide security to the battalion's rear, near checkpoint 71, oriented to the south.

- On order, screen to the east on the high ground near checkpoint 2, in order to prevent enemy attack of right flank or rear. [Ref. 6]

B. DETAILED SCENARIO DESCRIPTIONS

1. General Scenario Features

Each simulation scenario models the combat operations of 2/5 from the beach to the first major objective. Appendix A contains screen capture pictures taken during the scenario runs that show both forces' initial positions and movement at selected times for each scenario. The blue side represents the U.S. forces and the red side represents country Orange forces. The blue forces are generally aggregated to the platoon level, and consist of two mechanized infantry companies, weapons company assets, and Naval Surface Fire Support (NSFS) assets. In each scenario, they are opposed by red forces consisting of elements from a mechanized infantry battalion with Soviet Block weapons and equipment, damaged and dispersed from several weeks of intense bombardment by naval and air forces. The red forces are generally dispersed in squad sized elements, deployed in the general area of their parent company. The red forces delay and defend until they can determine which canyon the blue forces are attempting to penetrate. Their intent is to then rapidly reorganize their remaining forces for a counter-attack to destroy the blue beachhead. Table 1 lists the forces for this study.

Side	System/Unit	Quantity
Blue	Infantry Company	2
	AAV	26
	Weapons Company	1
	CAAT Teams	6
	TOW Section	2
	Destroyer (NSFS)	2
Red	Mech Inf Plt	9
	BTR-60	12
	122mm SP	6
	ZSU 23-4	2
	BRDM-2	3
	BMP-1	2

Table 1. Forces Listing.

2. CASE 1: No-UGVM Scenario

This case involves the general amphibious scenario and forces described above. This scenario is intended to provide a representation of a typical amphibious assault and subsequent combat operations. Example database entries for the systems and equipment used in this and all of the other scenarios are contained in Appendix B.

3. CASE 2: Standard UGVM Scenario

This scenario is similar to the no-UGVM scenario except for the addition of six UGVM systems. They conduct route reconnaissance, area and zone reconnaissance. During movement, the UGVM will use bounding overwatch by the CAAT and UGVM

teams to protect the scout force. Once a company occupies a support by fire position, the UGVM is deployed in a static position to provide early warning from an attack.

During this scenario, the UGVM's movement is restricted by its 4 km radio range and its requirement to maintain RF/LOS. There are some areas where reconnaissance is desired but not available because of the UGVM's speed and RF/LOS communications limitations.

The UGVM is modeled by modifying a HMMWV system to the appropriate values for the PP vehicle settings. The SP is modeled by adding a system as a passenger that has sensors with the appropriate characteristics for day and night driving and targeting cameras. This passenger system is able to call for indirect fires, thereby modeling the scout's use of the UGVM for targeting information. This passenger system is dismounted at the end of each PP movement leg, allowing it to use the targeting sensors only after the movement is completed. Dismount time penalties were included in the system specifications in the database to model the ORD specifications for deployment times. The defilade and pop-up attributes were set to allow the system to take advantage of naturally occurring cover and concealment while seeking appropriate stations to conduct RSTA operations.

The CS is modeled as a standard HMMWV except for a modification to the system to include a 4 km range sensor. This sensor is used to surrogate for the RF/LOS restriction by restricting the UGVM movements to those areas within the CS LOS from that 4 km sensor. This sensor was replaced with the driver's standard unaided eye sensor prior to simulation runs. Figure 4 shows the computation of an "allowed" route for the

UGVM using the 4 km sensor on the CS and LOS lines along the route requiring reconnaissance.

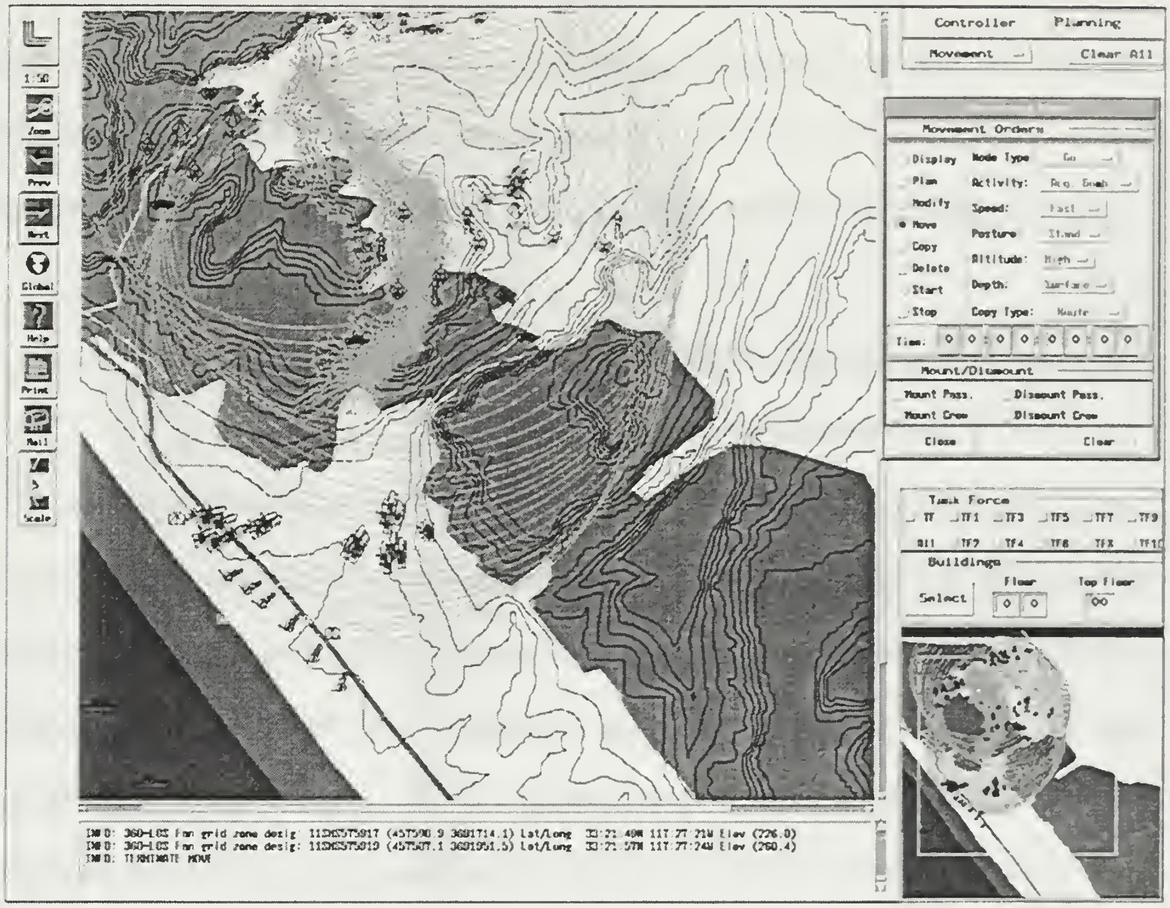

Figure 4. UGVM Route Planning.

4. CASES 3- 5: Increased Speed and Non-RF/LOS Modifications

These scenarios modify the standard UGVM scenario to allow increased mobility and coverage on desired routes by eliminating the 4 km restriction and increasing the speed of the UGVM in the model database.

The increased speed scenario requires only a simple change to the model database characteristics for the UGV system. The speed is increased from the ORD

requirement of 25 kph on paved road and 5 kph cross-country to 50 kph and 10 kph respectively.

The non-RF/LOS scenario requires new route planning in the model. The UGVMs are allowed to move along any path to support the reconnaissance effort, without the 4 km tether to the CS. No assumptions are made about how this non-LOS communication is accomplished, other than it does not depend on the CS location or LOS.

C. GENERAL MODEL PARAMETERS

1. Environmental Settings

The JCATS weather conditions parameters were set to the "9 kilometer day" settings included with the model. These settings are intended to simulate a day with 9 km of visibility and include a wide variety of parameters including wind, temperature, humidity and other detailed settings that impact the Night Vision and Electro-Optics Laboratory (NVEOL) acquisition model used by JCATS. The 9 kilometer day visibility is the weather condition specified for the performance parameters for the SP in the ORD. The natural lighting parameters were set to represent a moderately sunny day. The JCATS adverse weather parameters, which allow some specified weather events to degrade system performance, were not used.

2. Disabled Model Features

The following features and sub-models were disabled for all scenario runs in this study:

- Fatigue. This feature computes the energy levels for individual dismounted systems based on activity levels, combat stress, and conditioning and restricts activity if a system runs out of energy.
- Logistics. JCATS includes several features designed to simulate logistics, including ammunition and fuel resupply.
- Buildings/MOUT. JCATS includes building interior features, rubbling, and urban combat enhancements.
- Fratricide. JCATS has many features used by the fratricide model, including fatigue, secondary suppression, and combat stress.

These items were all eliminated from the model to speed processing and simplify data collection. While many of these features may be excellent candidates for inclusion in other more narrowly focused studies, none of them are critical for assessing the TUVM's performance in this simulation. Reducing unnecessary calculations and increasing run-time speeds allows for more runs to be conducted of each scenario selected for inclusion in the run matrix.

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III. ANALYSIS METHODOLOGY

A. RUN MATRIX

The no-UGVM scenario described in the previous chapter will be used as the base case for this study. A UGVM with ORD standard characteristics will then be added. Subsequent runs will modify speed and survivability characteristics. Table 2 shows the variations for each scenario run. Each scenario will be run ten times, using the JCATS Simulation Executive batch program. The batch program will run each scenario for a specified length of time, using a new random number seed for the model's stochastic events for each run.

			Communications		PP Speed	
Case	Base Case	UGV M	RF/LOS	NO RF/LOS	5 kph	10 kph
1	X					
2		X	X		X	
3		X		X	X	
4		X	X			X
5		X		X		X

Table 2. Scenario Run Matrix.

B. MEASURES OF EFFECTIVENESS (MOEs)

1. MOE1: Total Blue Acquisitions

This MOE captures the total number of acquisitions, at any level, by blue forces. These levels include:

- MOE1A: Detection. A system acquired at the detection level has been spotted.

- MOE1B: Classification. A system acquired at the classification level has been recognized at a general level, for example, as a tracked vehicle versus a wheeled vehicle.
- MOE1C: Recognition. A system acquired at the recognition level has been recognized as a specific type of vehicle or unit, for example, as a T-80 tank.
- MOE1D: Identification. A system acquired at the identification level has been identified as a specific system type or unit belonging to a specific side, for example, as a BMP-1 belonging to the red side.

Acoustic acquisitions are not included in this MOE, although JCATS does include an acoustic sensing function. The model does not initiate entity actions based on acoustic detections and they are treated more like alarms or warnings.

2. MOE2: Blue Acquisitions/Time

This MOE is subdivided by acquisition level to illustrate the quality as well as quantity of detections throughout the scenario. For example, acquisitions at the recognition and identification level are more important during the time when 2/5 is passing through the canyons than during the actions on the objective.

3. MOE3: Blue Losses

This MOE illustrates the potential for the UGVM system to prevent losses, especially within scout systems or lead elements. Losses over time are considered because of the importance of preserving combat power during the movement to the objective.

4. MOE4: Blue Kills

The possible types of kills in JCATS include direct fire, indirect fire, aviation and controller. All kill events are recorded separately for indirect and direct kills. This MOE attempts to capture indirect fire kills initiated by UGVMs sensing enemy targets without exposing friendly forces to hostile fire.

C. DATA COLLECTION

The JCATS configuration currently used at NPS does not allow for the use of the JCATS Analyst Workstation (AWS) to summarize the data from scenario runs into a format efficient for use in analyzing the MOEs just described. The AWS program also eliminates some of the data provided in the original output, reducing the fidelity of the analysis.

Instead, for this study, these files are sorted and summarized using commercial spreadsheet software. The actual output files used are 43 field, 256 character wide text files, in some instances exceeding 8000 records. The data collected for the analysis of the MOEs in this study is summarized by run number in Appendix C and discussed in the next chapter. The interested reader can obtain copies of the run data files from the author or Senior Lecturer Bard Mansager, by referencing JCATS Model UGV(A-E) at the NPS High-Resolution Model Laboratory.

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IV. DATA ANALYSIS

A. STATISTICAL ANALYSIS

1. Underlying Distribution

Before discussing the statistical implications of these results an attempt should be made to determine the nature of the underlying distribution. The analytical power of a simulation is amplified if information about the underlying distribution of the results can be determined.

The Kolmogorov-Smirnov (KS) test is one example of a method that provides information about a sample's underlying distribution. The KS test statistic is based on the maximum magnitude of difference between the sample cumulative distribution function (CDF) and the hypothesized CDF. [Ref. 8] This test is performed using the estimated sample mean and sample standard deviation. The test provides a p-value that is compared to a desired level of significance.

An important example of when knowledge of the underlying distribution is critical is for determining whether an observed difference between different samples is the result of random variations or is actually the result of some real change. By comparing mean values from different cases, using standardized procedures such as hypothesis testing, statistically significant differences may be discovered. Many of the standard tests for comparing the equality of sample means assume that the underlying distribution is normal, so the KS test will first be used to determine if the results from this study are distributed like a sample from a normally distributed population.

2. Testing for Equality of the Variances

An additional consideration for using many of the standard statistical tests is equality of the variances between samples. The F test is used to compare the variances from two samples with unknown distribution parameters. [Ref. 7] The F test assumes that the two samples are independent and come from normal distributions. No assumption is required about the means.

The F test statistic is formed by the ratio of the two sample variances. For a given level of significance (α), the test statistic (*TS*) is compared to a critical value of the F distribution.

$$TS = \frac{s_y^2}{s_x^2} \tag{1}$$

When n is the size of a sample from the distribution of X and m is the size of a sample from the distribution of Y, the F test rejects the null hypothesis if:

$$TS \text{ is either } \begin{cases} \leq F_{\frac{\alpha}{2}}, m-1, n-1 \\ or \\ \geq F_{1-\frac{\alpha}{2}}, m-1, n-1 \end{cases} \tag{2}$$

where $F_{\frac{\alpha}{2},m-1,n-1}$ and $F_{1-\frac{\alpha}{2},m-1,n-1}$ are the $\frac{\alpha}{2}$ and $1-\frac{\alpha}{2}$ quantiles, respectively, of the F distribution with *m-1* and *n-1* degrees of freedom.

3. Testing for Equality of the Means

The t-test, based on the Student's t-distribution, is a commonly used tool for testing the difference between mean values from different samples. The t-test requires normality, equality of variances, and independence.

The t-test requires normality, equality of variances, and independence [Ref. 9]

The test statistic for the t-test is:

$$TS = \frac{\bar{x} - \bar{y}}{S_p \sqrt{\frac{1}{m} + \frac{1}{n}}} \tag{3}$$

When n is the size of a sample from the distribution of X and m is the size of a sample from the distribution of Y, the decision rule rejects the null hypothesis if:

$$TS \text{ is either } \begin{cases} \leq -t_{\frac{\alpha}{2}, m+n-2} \\ or \\ \geq +t_{\frac{\alpha}{2}, m+n-2} \end{cases} \tag{4}$$

where $\pm t_{\frac{\alpha}{2}, m+n-2}$ are the $\frac{\alpha}{2}$ and $1-\frac{\alpha}{2}$ quantiles, respectively, of the t-distribution with $m+n-2$ degrees of freedom.

If equality of the variances is rejected by the F-test, the problem becomes more difficult. An adjusted degree of freedom value must be computed. [Ref 7]. Equation 5 provides the value then used in the t-test.

$$v = \frac{\left({s_x^2}/{m} + {s_y^2}/{n} \right)^2}{\left[{\left(s_x^2/m\right)^2}/{(m-1)} \right] + \left[{\left(s_y^2/n\right)^2}/{(n-1)} \right]} \tag{5}$$

The small sample size used in this study may also explain deviations from the required assumptions for the previously described tests. The tests may still be valuable,

however, because the two-sample t-test is robust to mild departures from the assumptions, especially when the sample sizes are equal, as in this case. [Ref. 9]

Even if the assumptions required for the t-test are present or their absence explainable, a rigorous examination can also include analysis methods that do not require specific information about the underlying distribution. Such non-parametric tests, such as the Wilcoxon rank sum test, can also be used to enhance an analysis based on parametric methods like the Student's t-test for testing differences in the mean.

If data consist of two random samples, a sample X of size m, and a sample Y (independent of sample X) of size n, then the Wilcoxon rank sum statistic is the sum of the ranks of X in the combined sample, computed by subtracting the hypothesized difference in means (Δ_0) from the X values and ranking the results:

$$w = \sum_{i=1}^{m} r_i \tag{6}$$

where r_1= the rank of (x_i-Δ_0) in the combined sample. [Ref. 10]

This statistic can then be used for a non-parametric test of location shift between the parent populations. If the sample size of both X and Y exceed 8, a normal approximation to W can be used and the Wilcoxon rank sum statistic takes parameters :

$$\begin{aligned} \mu_w &= \frac{m(m+2n+1)}{2} \\ \sigma_w^2 &= \frac{mn(m+n+1)}{12} - \frac{mn}{12(m+n)(m+n-1)} \sum (t_i - 1)(t_i)(t_i + 1) \end{aligned} \tag{7}$$

where t_i is the number of tied rank observations in the ith set of tied ranks if ties occur.

The test statistic:

$$Z = \frac{W - \mu_w}{\sigma_w} \tag{8}$$

then has approximately the standard normal distribution. [Ref. 9]

B. STATISTICAL RESULTS

The KS test indicated that all of the samples could be from a normal distribution. After computing the appropriate degrees of freedom for the t-test using Equation 3, the t-test and Wilcoxon test were compared for significance at the 95% level. These results are listed in Tables 3 and 4. The p-values for these results are contained in Appendix D.

		2	3	4	5
MOE1	1	YES	YES	YES	YES
	2		NO	YES	YES
	3			YES	YES
	4				NO
MOE2	1	YES	YES	YES	YES
	2		YES	NO	YES
	3			NO	YES
	4				YES
MOE3	1	NO	NO	YES	YES
	2		NO	YES	YES
	3			NO	NO
	4				NO

Table 3. T-test Significance Results.

		2	3	4	5
MOE1	1	YES	YES	YES	YES
	2		NO	YES	YES
	3			YES	YES
	4				NO
MOE2	1	YES	YES	YES	YES
	2		YES	NO	YES
	3			YES	YES
	4				YES
MOE3	1	NO	NO	YES	YES
	2		NO	YES	NO
	3			NO	NO
	4				NO

Table 4. Wilcoxon Test Significance Results.

Note that the t-test and the Wilcoxon Test generally agree. The tests agree that the base case differs significantly from cases 2-5. Neither test supports a difference on MOE3 between cases 3-5.

An analysis of variance (ANOVA) test and Kruskal-Wallis Rank sum test analysis both indicate highly significant differences. This offers additional support for the improvement in performance indicated for the TUVM scenarios.

C. SUMMARY AND STATISTICS

Table 5 shows a summary of the results of the data collection. A more complete picture of the data gathered from the scenarios is contained in Appendix C.

CASE	MOE1		MOE1A		MOE1B		MOE1C		MOE1D		MOE3		MOE4	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	327.80	59.92	118.00	25.58	74.20	13.96	60.90	13.38	74.00	15.21	34.40	3.10	8.80	4.32
2	160.10	17.08	52.60	8.53	38.60	8.92	25.10	4.01	43.80	5.16	42.10	1.10	8.50	2.92
3	169.00	16.49	59.40	8.78	32.00	6.53	29.50	4.58	48.10	4.12	40.40	1.17	6.00	3.68
4	92.80	9.27	18.40	4.88	19.30	4.83	19.10	4.12	36.00	4.08	42.90	2.28	4.30	2.31
5	98.60	14.09	23.40	7.03	17.00	6.60	24.30	6.25	33.90	7.20	48.70	3.27	3.90	2.02

Table 5. Summarized MOE Results.

A brief examination of these results reveals a relatively significant deviation from the base case for all of the MOEs. Even the seemingly large standard deviations in the base case (Case 1) do not suggest a variability that would fully explain the changes in the values reported for the UGVM cases (Cases 2-5). Most notably, the difference in MOE1 (total acquisitions) is relatively dramatic, with a difference of 229 acquisitions between the most capable UGVM scenario (Case 5) and the base case.

Unexpectedly, the addition of a specialized sensor system, the TUVM, actually resulted in a decrease in the number of detections for all cases. The potential reasons for this result becomes clear when MOE3 (Blue losses) and MOE4 (Blue kills) are examined.

Figure 5 shows the relationship between total acquisitions and kills for Cases 1 and 5. This spikes in both acquisitions and kills provide an indicator of the timeline for this scenario. At approximately the 30th minute, E 2/5 encounters some resistance in the canyon, and comes under indirect fire. At the 65th minute, G 2/5 has fought through the end of Las Pulgas Canyon and has encountered moderate resistance. At the 100th minute, E 2/5 begins movement up to the objective, with a corresponding increase in acquisitions and combat activity as they near the objective.

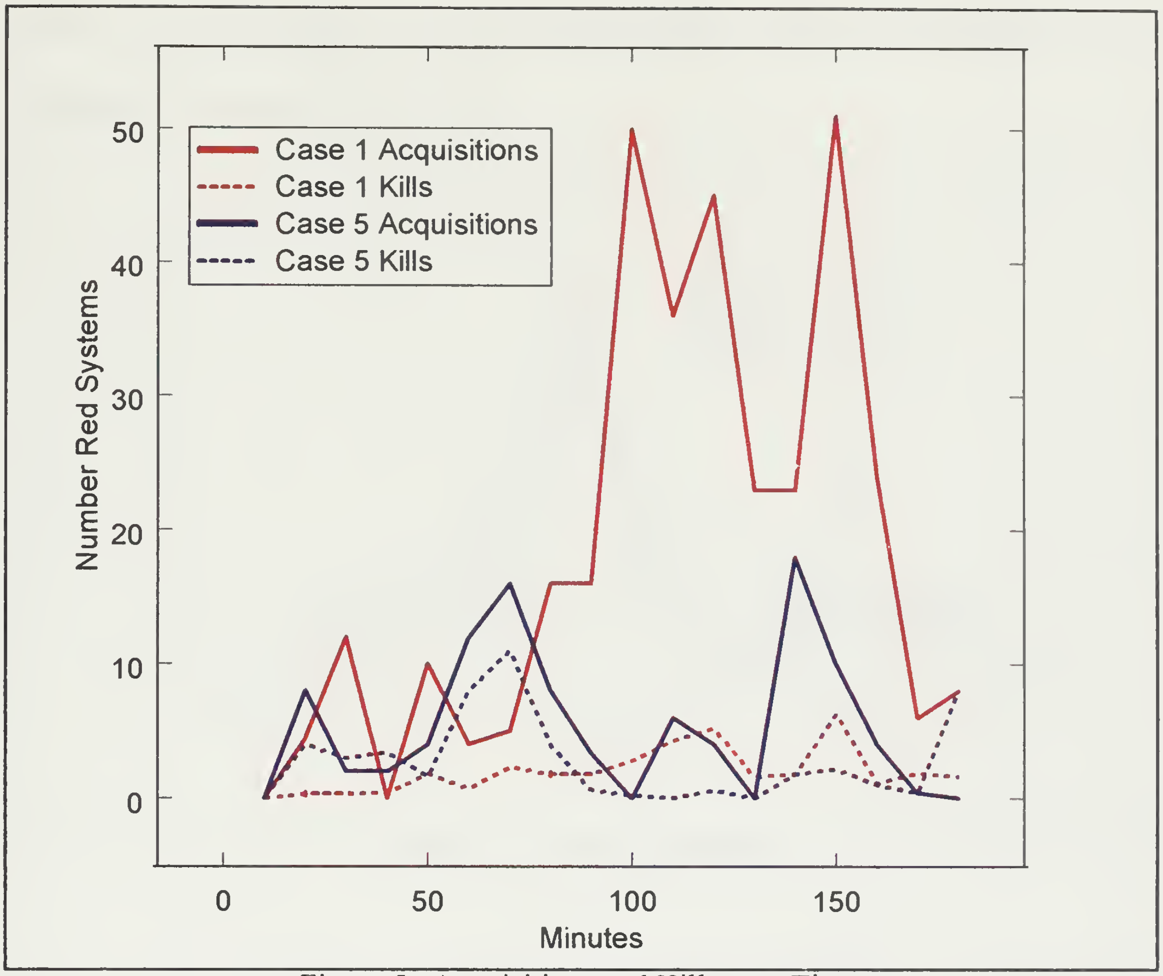

Figure 5. Acquisitions and Kills over Time.

The spikes in acquisitions and kills for Case 1 are generally preceded by a smaller spike in acquisitions from Case 5. The TUVM equipped force in Case 5 is able to acquire targets faster and effectively engage a greater proportion of acquired targets than the base case forces. The target rich environment faced by the base case forces provides many more *opportunities* for Red systems to be acquired, as shown by the dramatic spike in total acquisitions for the base case in Figure 5. The higher kill rate for the base case near the objective (150th minute) is also a reflection of more available targets and because of fewer kills early in the scenario. The general trends suggested by the comparison of the most capable force, Case 5, against the base case are consistent throughout all of the

cases, as shown by Figure 6 and 7, a graph of the remaining cases total kills and acquisitions compared to the base case.

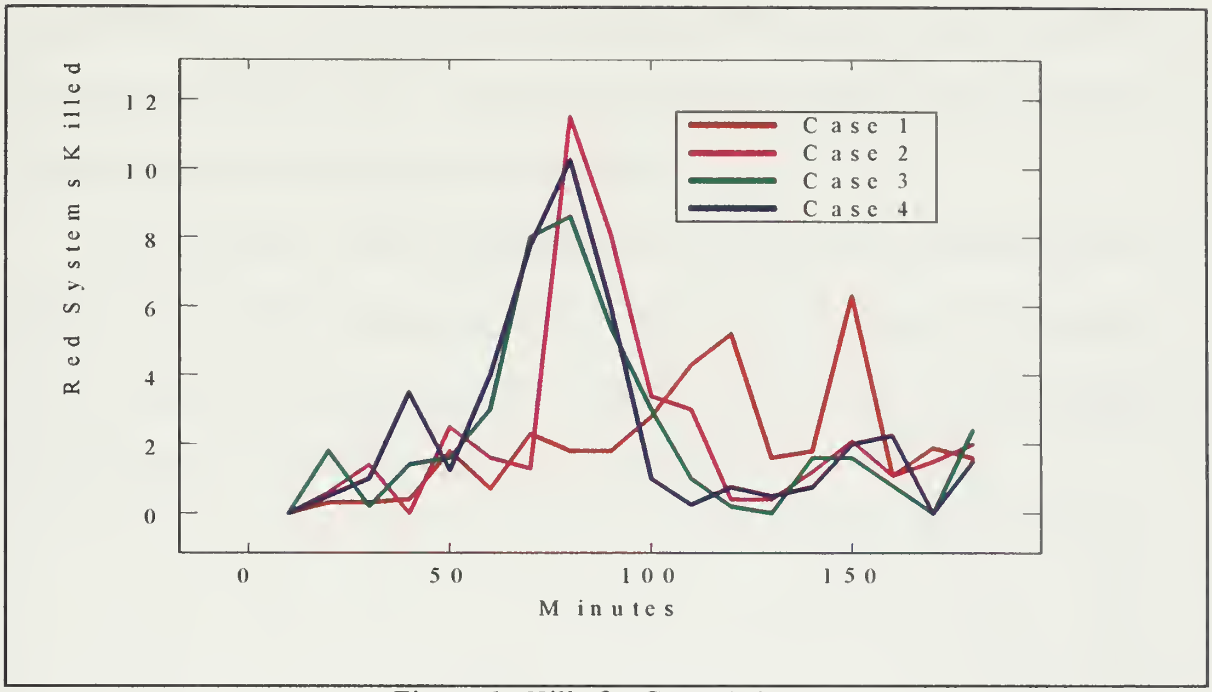

Figure 6. Kills for Cases 1-4.

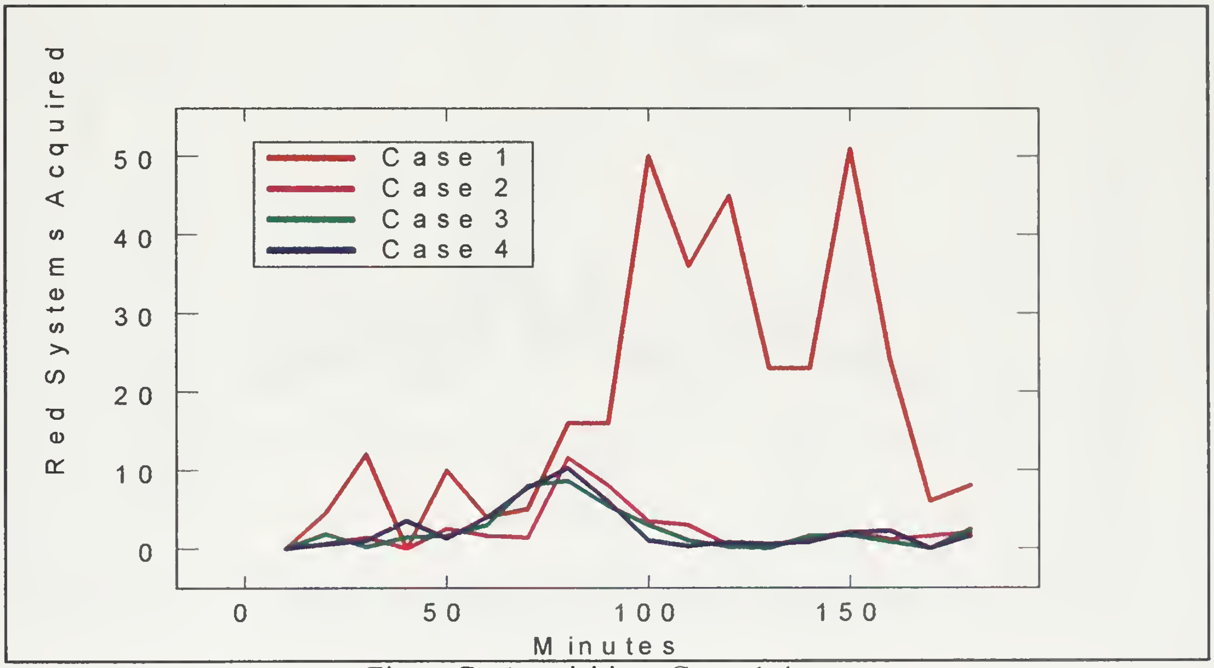

Figure 7. Acquisitions Cases 1-4.

The relationship demonstrated by these results suggests that some other measure than total detections may be necessary. Simply dividing the total acquisitions by the number of kills will fail to capture the time component. Because each enemy system may be acquired several times by any remaining blue system, early kills reduce the number of acquisition opportunities much more than later kills.

The breakdown of total acquisitions into the four levels of acquisition did not produce any particularly interesting results. Plots of the individual levels generally follow the shape of total acquisition when graphed over time as can be seen from Figure 8, illustrating the breakdown by acquisition level for Case 2.

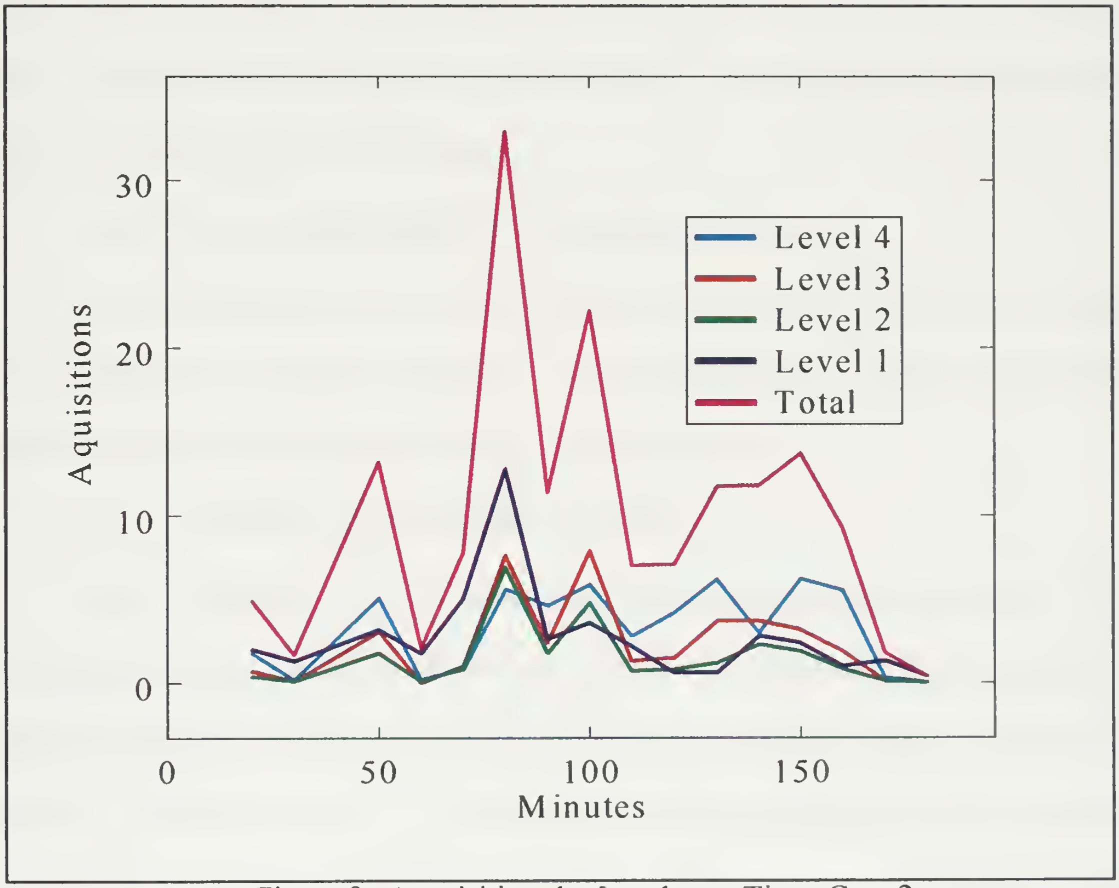

Figure 8. Acquisitions by Level over Time: Case 2.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The analysis reveals that there is a significant difference between the scenarios with a TUVM and those without. The TUVM modeled in case 5 offers significant improvements in both MOE1 and MOE3, both over the base case and the competing TUVM cases. There is no data to support a conclusion that the case 5 TUVM reduces blue losses more than the other TUVMs.

Unfortunately, the most significant difference, MOE1, does not have the data collected from this analysis that would support a more detailed examination of the causes of the drop in acquisitions. The graphical analysis of kills and losses over time indicates that the large drop in acquisitions may be explained by the reduction in opportunities rather than the ability to acquire targets.

B. TACTICAL EMPLOYMENT CONSIDERATIONS

The research prompted by this thesis and the discussions with Marine Corps and Army officers that invariably followed the author's questions have generated the following tactical employment considerations for the TUVM.

1. Long-term Remote Observation Posts

Many of the officers the author spoke to expressed an interest in using the TUVM in a static or semi-static position for several days prior to an assault. The introduction of limited autonomous capabilities were especially important for this mission. The ability to provide a warning or alarm to a remote operator when some element of the TUVM's environment has changed was considered crucial. A clear majority considered the need

for continuous, active operation as the TUVM's most serious drawback on this type of mission.

2. Laser Designating

Adding a laser designator should be a priority. A catchphrase currently popular in the American military is, "If we can see you we can kill you." Unfortunately, this may be overly optimistic. Observation is not the same as targeting. A significant weakness of most combined arms efforts is the inability of observers to accurately locate a target. Even with precision guided munitions, the observer must have a reasonably good target location for the mission to be effective. With the TUVM's ability to observe targets, it seems to the author that it is a tremendous waste not to give it more of a role in improving our ability to actually hit the target. Additionally, the use of a laser to designate for precision guided munitions requires the operator to expose himself on the battlefield. The laser must have an unobstructed LOS to the target. A mission that required an operator to expose himself to laser designate for a target remotely detected by a TUVM seems counterproductive.

3. Deployment of Remote Sensors

For many static missions, the TUVM would be too valuable to risk being left unprotected for too long in a hostile area. However, if the TUVM had the ability to deploy remote sensors, the risk associated with both obtaining the RSTA information and deploying the sensors could be reduced. The remote sensors could be placed with great precision and detail, and yet no human would be placed at risk.

C. RECOMMENDATIONS

1. Reassessing the Role of Counting Acquisitions

The attempt to use total acquisitions as a MOE in this study revealed a potential flaw in the use of acquisition volume as a meaningful measure a force's ability to effectively conduct RSTA. Any study that uses related measures should re-evaluate the impact of increasing opportunity for acquisition versus increased effectiveness of acquisition.

2. JCATS Modeling

Numerous future modeling projects are suggested by the work done for this thesis. Many are directly connected to the enhanced high-resolution capabilities of the JCATS model. The following is a brief list of the topics the author believes could be addressed using the JCATS Model available at the Glascow High Resolution Modeling Laboratory:

- Investigate the human factors concerning the payoff between the teloperation of the TUVM and the stress and fatigue associated with performing a scout mission. JCATS includes the ability to consider energy level, second order effects from suppression and enemy contact, and a wide variety of human factor settings for individual systems.
- Conduct a detailed study to trace each kill event in a scenario back to the initial observation that promoted it. Use this information to attempt to evaluate the importance of the various levels of acquisition and the costs (in blue losses) associated with each observation that leads to a kill event. The

JCATS data files record scenario events to a degree of fidelity that will permit this sort of analysis.

- Conduct a larger study with more detailed ground and air forces to gather a wider variety of acquisition events. Simultaneous observations of enemy systems with varying threat levels could be intentionally included in this scenario to evaluate the ability of operators and commanders to use the abilities added by the TUVM.

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APPENDIX A. SCENARIO SCREENS

The following pictures are screen captures from the JCATS simulations, illustrating movement, positioning, and fields of view. Screens from the planning stages of the simulation runs are included for some illustrations.

Figure A-1 shows the primary routes from Red Beach to the objective. The positioning of the Red forces is also clearly visible.

Figure A-2 shows where the key combat takes place, clearly indicated by the killed systems concentrated in a few areas.

Figure A-3 is a demonstration of the forward observer feature in action. The Red force mortars are in direct support of a Red FO. The orange arrow coming from the mortar in the center-left of the picture indicates that it has just fired rounds.

Figure A-4 is G 2/5's support of the E 2/5 main effort from the SBF position with a base of fire from their direct fire systems. JCATS allows planned direct fire events to support this type of scenario.

Figure A-5 is a TUVM on high ground identifying Red systems prior to E 2/5's passage through the canyon.

Figure A-6 shows one TUVM in overwatch as another identifies enemy mortars.

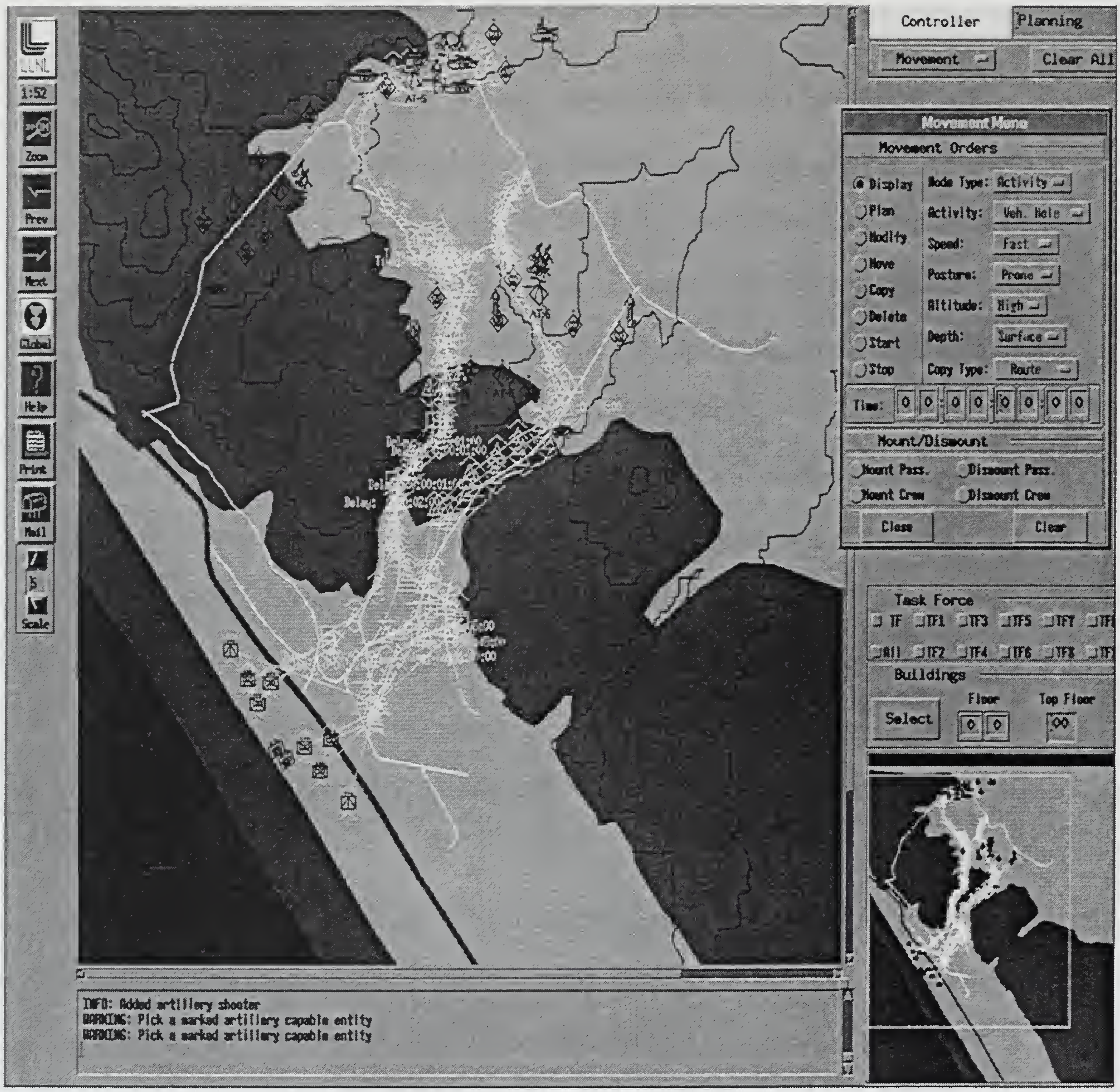

Figure A-1. The Routes from Red Beach toward the Objective.

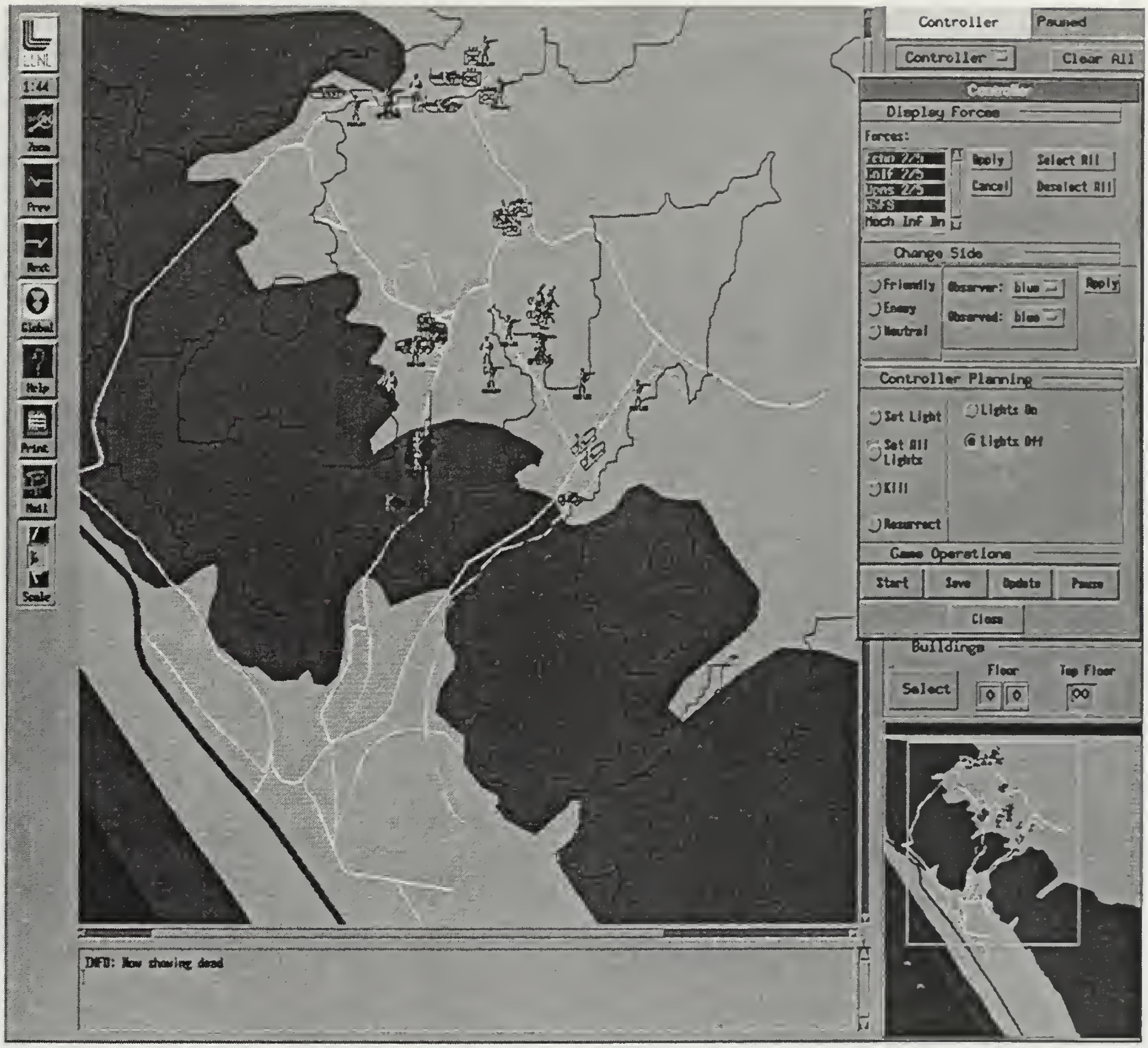

Figure A-2. Killed Systems Displayed during a Base Case Run in JCATS.

Figure A-3. Red Indirect Fire Supports a Forward Observer.

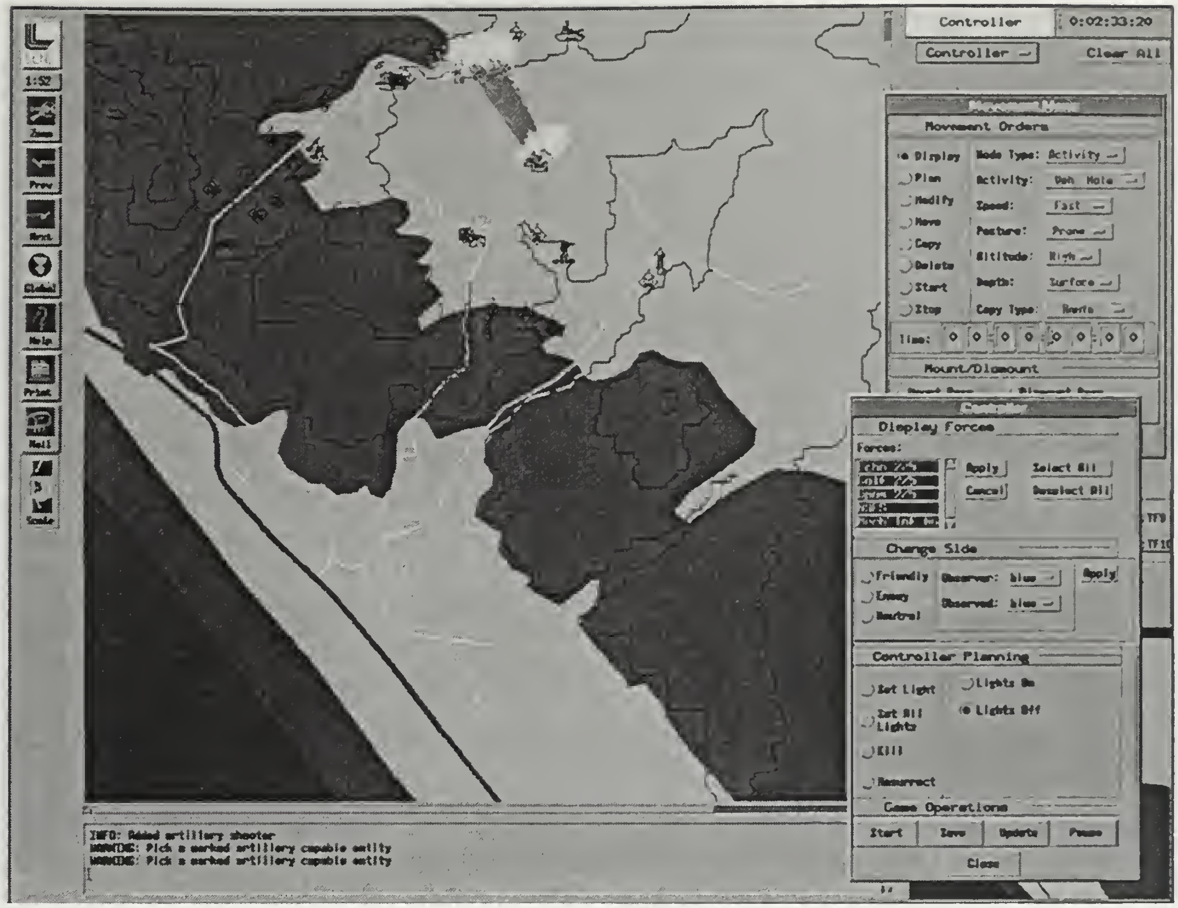

Figure A-4. SBF Position Begins Firing.

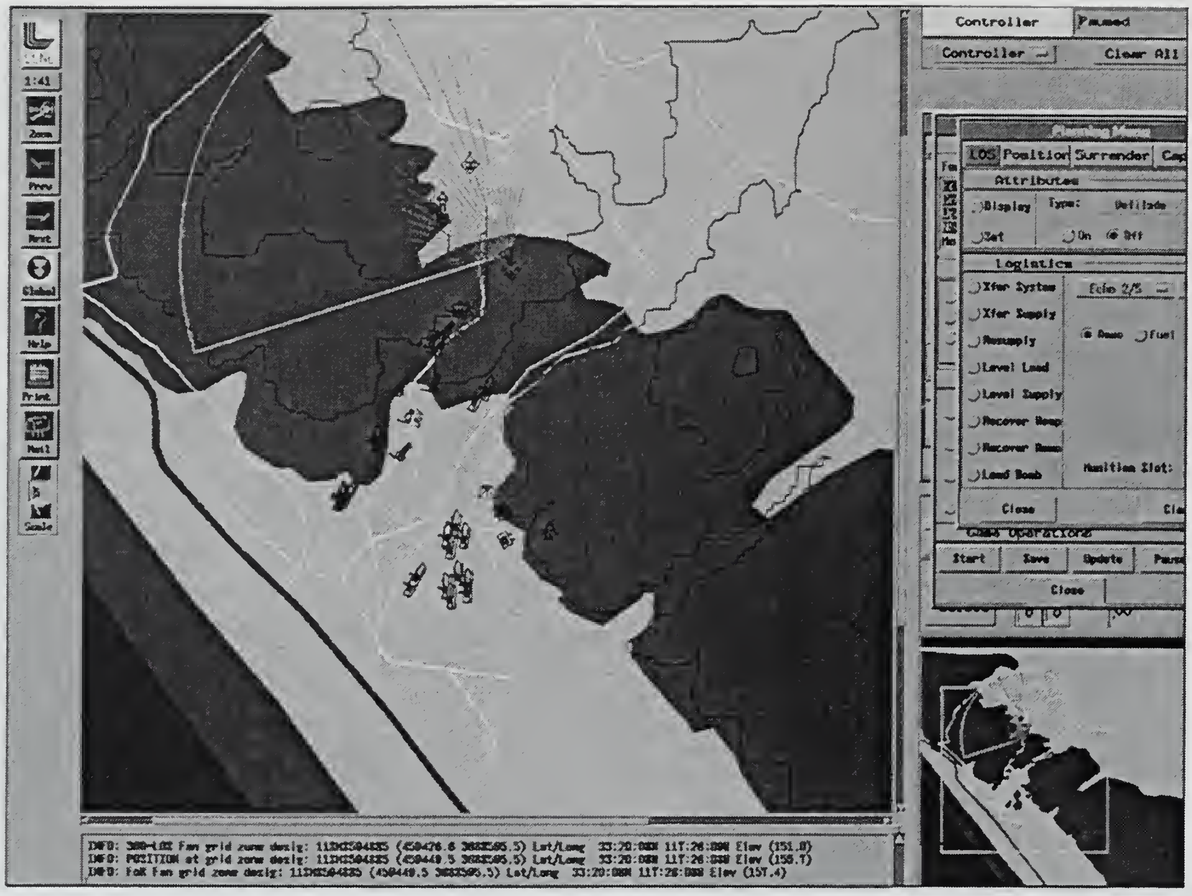

Figure A-5. A TUVM Deployed to High Ground.

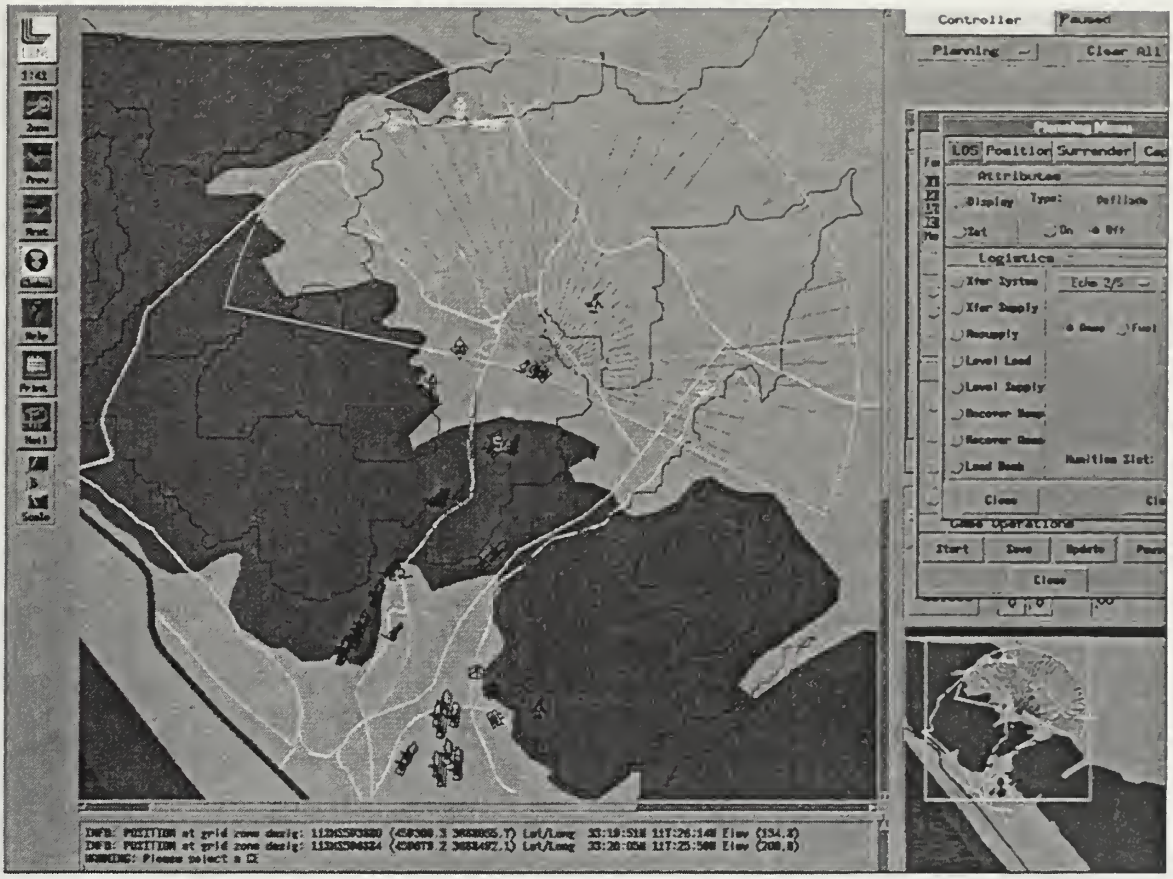

Figure A-6. A TUVM in Overwatch Position.

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APPENDIX B. JCATS DATABASE

A. UGVM SYSTEM DATABASE RECORDS

The following records are the detailed descriptions from the JCATS database for the UGVM specific model entities. The records are formatted to correspond to the graphical user interface of the JCATS Vista Scenario Editor program. Detailed explanations for the specific entries can be found in Reference 4.

1. System Class: UGV

Tab: General

Mobility Type: Four_By_Four

Mission : ANTI TROOP

Laser Designator :

Forward Observer :
Partial Defilade (m) : 0.5
Target Index: : 4
Full Defilade (m) : 0.1
NVEOL Target Class: 1

Artillery Vulnerability Category

Open: 14
Protected: 14

Symbols
Classification (level 2): 175
Identification (level 4): 175

Mount Time (sec) : 10
Fuel Transfer Rate (gal/min) : 0.17
Mount/Transfer Radius (m) : 50
Munition Transfer Rate (lbs/min): 3.67
Dismount Time (sec) : 1800

Dismount Radius (m) : 50

Dismount/All Time (sec) : 1800
Dismount/All Offset (m) : 1

Pairing Interval (sec): 10
Peripheral Acquisition Weight (%): 60

Tab: Detectability

Detection Signatures
Unattended Sensors:
Radar:
Sonar:

Reflectivity: 0.2

Tab: Vehicle Data

Length (m)	: 1.2	Observation Height (m)	: 1.75
Width (m)	: 1	Passenger Height (m)	: 1.5
Height (m)	: 1	Minimum Crew Size	: 0
Draft (m)	: 0	Maximum Crew Size	: 1
Weight (lbs)	: 300.0	Head Shot Angle (deg)	: 10
Blockage Radius (m)	: 1	Suppr Protect (dist mult)	: 2

Passengers Can Acquire : Yes
Passengers Can Shoot : Yes
Passengers Mount Inside: No

Basic Fuel Load (gal): 25

Initial Resupply Load
Ammo (lbs): 0 Fuel (gal): 0

Carry Capacity

Init Load	Extra Cap	Total
0	1000	1000
0	0	0
0	4	4

Tab: Behavior on Ground

Movement Speeds (km/hr)	Fuel Consump Rates (gal/hr)	Bhvr on Slope (% grade)
Slow : 2	Slow : 2	Max Cont Down Grade : 60
Medium : 5	Medium : 2.5	Max Cont Up Grade : 60
Fast : 25	Fast : 3	Minimum Grade Change: 1
Maximum: 25	Stationary: 0	

Tab: Behavior on Water

	Swim Speeds (km/hr)	Ford Speeds (km/hr)	Fuel Consumption Rates (gal/hr)
Slow :	0	1	Slow : 0
Medium :	0	1	Medium : 0
Fast :	0	1	Fast : 0
Maximum:	0	1	Stationary: 0

Max Ford Depth (m) : 0.1
Max Current Speed (km/hr): 1

Tab: Barrier Data

Barrier Interaction Speeds (km/hr)

Penetrate Wire : 0
Breach Wire : 0.1
Penetrate Submerged: 0
Breach Submerged: 0
Penetrate Ditch : 0
Breach Ditch : 0
Penetrate Float : 0

Breach Float : 0
Penetrate Rubble: 0 Breach Rubble: 0 Penetrate Hulk : 0.1
Clear Mines : 0.0

Barrier Activity Times (sec)

Miscellaneous
Dig Vehicle Hole: 0 Dig/Stack Sandbags : 0 Move Hulk: 0
System Breach Code: 2
Dig Foxhole : 0 Create Vehicle Fortification : 0

Tab: Stations

Station: 1 Sensor: UGV Driving Optical Sight

Weapon Munition Rounds

Station: 2 Sensor: UGV Driving Thml Sight

Weapon Munition Rounds

2. System Class: UGV-FO

Tab: General

Mobility Type: Dismounted

Mission : ANTI TANK

Laser Designator :

Forward Observer : trained
Partial Defilade (m) :1.5
Target Index: : 4
Full Defilade (m) : 1
NVEOL Target Class: 4

Artillery Vulnerability Category

Open: 1
Protected: 4

Symbols
Classification (level 2): 86
Identification (level 4): 86

Mount Time (sec) : 10
Fuel Transfer Rate (gal/min) : 0
Mount/Transfer Radius (m) : 1
Munition Transfer Rate (lbs/min): 0
Dismount Time (sec) : 10

Dismount Radius (m) : 1

Dismount/All Time (sec) : 10
Dismount/All Offset (m) : 1

Pairing Interval (sec): 10
Peripheral Acquisition Weight (%): 50

Tab: Detectability

Detection Signatures
Unattended Sensors:
Radar:
Sonar:

Reflectivity: 0.2

Tab: Dismounted Data

Weight lbs : 100
Combat Effectiveness : 1
Volume (cu/m): 1
Fatigue Class Name : Well Trained
Fuel Carry (gal) : 0
Engineering Ability (%): 0

Carry Weight (lbs) : 1

Carry Volume (cu m): 0.75

Max Energy Level (cal): 40000
Initial Energy Level (% of max): 100

Tab: Behavior on Ground

Human Posture Table

Posture	Silhouette sq m	Height m	Max km/hr	Fast km/hr	Med km/hr	Slow km/hr
Prone	1	1.5	0	0	0	0
Crouch	1	1.5	0	0	0	0
Prone	1	1.5	0	0	0	0

Behavior On Slope (% grade)
Max Cont Down Grade: 60
Max Cont Up Grade: 60
Minimum Grade Change: 1

Tab: Behavior on Water

	Swim Speeds (km/hr)	Ford Speeds (km/hr)
Slow :	0	0
Medium :	0	0
Fast :	0	0
Maximum:	0	0

Max Ford Depth (m) : 0
Max Current Speed (km/hr): 0

Tab: Barrier Data

Barrier Interaction Speeds (km/hr)

Penetrate Wire : 0 Breach Wire : 0 Penetrate Submerged: 0
Breach Submerged: 0
Penetrate Ditch : 0 Breach Ditch : 0 Penetrate Float : 0
Breach Float : 0
Penetrate Rubble: 0 Breach Rubble: 0 Penetrate Hulk : 0
Clear Mines : 0

Barrier Activity Times (sec) Miscellaneous
Dig Vehicle Hole: 0 Dig/Stack Sandbags : 0 Move Hulk: 0 System
Breach Code: 0
Dig Foxhole : 0 Create Vehicle Fortification : 0

Tab: Stations

Station: 1 Sensor: Impvd Opt
Weapon Munition Rounds
Station: 2 Sensor: Impvd Thml
Weapon Munition Rounds

3. System Class: UGV-TH

Tab: General

Symbols
Mobility Type: Four_By_Four Classification (level 2): 34 Identification (level 4): 34

Mission : No Mission
Mount Time (sec) : 10 Fuel Transfer Rate (gal/min) : 1.67
Laser Designator : Mount/Transfer Radius (m) : 50
Munition Transfer Rate (lbs/min): 3.67
Forward Observer : Dismount Time (sec) : 1800
Partial Defilade (m) : 2
Target Index: : 4 Dismount Radius (m) : 50
Full Defilade (m) : 2
NVEOL Target Class : 4 Dismount/All Time (sec) : 1800
Dismount/All Offset (m) : 1

Artillery Vulnerability Category Pairing Interval (sec): 10
Peripheral Acquisition Weight (%): 25

Open: 14
Protected: 13

Tab: Detectability

Detection Signatures	Reflectivity: 0.2
Unattended Sensors:	
Radar:	
Sonar:	

Tab: Vehicle Data

Length (m) : 6	Observation Height (m) : 1.75
Width (m) : 2.5	Passenger Height (m) : 1.5
Height (m) : 2	Minimum Crew Size : 0
Draft (m) : 0	Maximum Crew Size : 4
Weight (lbs) :8000.0	Head Shot Angle (deg) : 45
Blockage Radius (m) : 2.5	Suppr Protect (dist mult) : 2

Passengers Can Acquire : Yes
Passengers Can Shoot : Yes
Passengers Mount Inside: Yes

Basic Fuel Load (gal): 25

Initial Resupply Load
Ammo (lbs): 0 Fuel (gal): 0

Carry Capacity

Init Load	Extra Cap	Total
0	2000	2000
0	0	0
0	4	4

Tab: Behavior on Ground

Movement Speeds (km/hr)		Fuel Consump Rates (gal/hr)		Bhvr on Slope (% grade)
Slow :	7	Slow :	2	Max Cont Down Grade : 30
Medium :	25	Medium :	2.5	Max Cont Up Grade : 30
Fast :	40	Fast :	3	Minimum Grade Change: 1
Maximum:	88	Stationary:	0	

Tab: Behavior on Water

Swim Speeds (km/hr)		Ford Speeds (km/hr)	Fuel Consumption Rates (gal/hr)	
Slow :	0	15	Slow :	0
Medium :	0	15	Medium :	0
Fast :	0	15	Fast :	0

Max Ford Depth (m) : 1
Max Current Speed (km/hr): 10

Maximum: 0 15 Stationary: 0

Tab: Barrier Data

Barrier Interaction Speeds (km/hr)

Penetrate Wire : 1 Breach Wire : 0.1 Penetrate Submerged: 0
Breach Submerged: 0
Penetrate Ditch : 1 Breach Ditch : 0 Penetrate Float : 0
Breach Float : 0
Penetrate Rubble: 1 Breach Rubble: 0 Penetrate Hulk : 0.1
Clear Mines : 0.027

Barrier Activity Times (sec)

Miscellaneous
Dig Vehicle Hole: 0 Dig/Stack Sandbags : 0 Move Hulk: 0.5
System Breach Code: 2
Dig Foxhole : 0 Create Vehicle Fortification : 0

Tab: Stations

Station: 1 Sensor: Unaided Eye
Weapon Munition Rounds

B. CHARACTERISTICS FILE EXAMPLES

The following are example records from the various classes of database entries in the JCATS characteristics files used in this study. The remaining elements from the database are too cumbersome to list all of them in this document. A complete printout or electronic copy of the database is available upon request from the author.

The following two records provide examples of two different sensors from the model.

1. Sensor Class: Impvd Opt

Tab: General

Kind: NVEOL Optical	
Minimum Range (m):	0
Maximum Range(m):	4000
Field of View (degrees):	9.000
Acquisition Scan Interval (sec):	5
Acquisition Scans per LOS Check:	5
Max Concurrent Acquisitions:	20

Tab: NVEOL Contrasts

	Cycles Per Milliradian	Temp/Optical Contrast
1	0.23	0.06
2	1	0.09
3	1.5	0.1
4	2.2	0.2
5	3.1	0.3
6	4.2	0.4
7	5.1	0.48
8	6.2	0.55
9	7	0.6
10	7.9	0.62
11	8.4	0.66
12	8.6	0.68
13	8.8	0.7
14	9	0.72
15	9.15	0.76
16	9.25	0.81
17	9.45	0.9
18	9.7	0.95
19	10.1	1
20	10.4	1.3

2. Sensor Class: Impvd Thml

Tab: General

Kind: NVEOL Thermal	
Minimum Range (m):	0
Maximum Range(m):	4000
Field of View (degrees):	7.5000
Acquisition Scan Interval (sec):	5

Acquisition Scans per LOS Check: 5
Max Concurrent Acquisitions: 20

Tab: NVEOL Contrasts

	Cycles Per Milliradian	Temp/Optical Contrast
1	0.02	0.002
2	0.5	0.006
3	1	0.011
4	1.5	0.018
5	2	0.025
6	2.5	0.035
7	3	0.049
8	3.5	0.065
9	4	0.088
10	4.5	0.125
11	5	0.18
12	5.5	0.265
13	6	0.4
14	6.5	0.64
15	7	1.05
16	7.5	1.79
17	8	3.19
18	8.5	5.94
19	8.5	5.94

2. Characteristics-Forward Observers

Class Name: trained
Mission Name: ANTI TANK
Min range (m): 80
Max Range (m): 5000
Contact Time (sec): 30
Adjust Time (sec): 15
Mean Range Error (mils): 5
Mean Deflection Error (mils): 2
Fire for Effect Range (m): 2

Volley Data

	Vulnerability Category	Number of Volleys	Munition Class
1	Pers Stand	2	HE
2	Pers Prone	3	HE
3	Pers Prot	3	HE
4	Pers Foxhole	3	HE
5	Tank Medium	4	HE

6	Tank Heavy	4	HE
7	Tank Launched Brdg	4	HE
8	APC Tracked Heavy	4	HE
9	APC Tracked Med	4	HE
10	APC Heavy	4	HE
11	APC Wheeled Medium	4	HE
12	APC Wheeled Light	4	HE
13	Truck Wheeled Medium	4	HE
14	Truck Wheeled Light	4	HE
15	Truck Wheeled Heavy	4	HE
16	Arty SP Light	4	HE
17	Arty SP Medium	4	HE
18	Helo Med I	4	HE
19	Helo Med II	4	HE
20	MRL Heavy	4	HE
21	Helo Med III	4	HE
22	ADW Tracked I	4	HE
23	ADW Tracked II	4	HE
24	ADW Launcher Wheeled	4	HE
25	Air Defense Track	4	HE

3. Characteristics-Weapons

Weapon Class: MK19

Primary Suppression Weapon: Yes
System Must Stop to Shoot: No
System Must Stop to Shoot: No
System Must Stop to Shoot: No
Reliability (%): 100

Detection Effects

	Size Multiplier	Duration sec
Open	2	30
City	2	30
Wood	2	15

Weapon Activity Times (sec)

Maximum Speed for Direct Mode (km/hr)

Setup Time: 0 Tear Down Time: 0

Weapon Considered Stationary: 0

Minimum Cycle Time: 1

Sustained Cycle Time: 20

Target Considered Stationary: 5.5

Lay Time: 5 Reload Time: 30

4. Characteristics-Environment

Class:	9km day
Relative Humidity (%):	20
Weather ID:	15
Wind Direction (deg):	240
Wind Velocity (km/hr):	3
Weather Temperature (deg C):	23.89
Optical Contrast:	0.35
Temperature Gradient (deg C):	0
Cloud Cover Height (m):	0

Extinction Coefficients

Optical:	0.0004	0.0004
Thermal:	0	0

Sky to Ground Angles

2578 : 5.8 5156 : 5.8 7734 : 5.8 10313 : 5.8

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APPENDIX C. DATA SUMMARY

Tables 6 and 7 summarize the raw data from the JCATS runs. Space and formatting issues prohibit the inclusion of the detailed records with this thesis. However, the actual data files are available upon request from the author.

CASE	MOE1	MOE1A	MOE1B	MOE1C	MOE1D	MOE3	MOE4
1	351	116	80	60	95	35	14
	316	116	81	62	57	33	8
	289	116	67	39	67	33	12
	326	108	70	64	84	37	4
	401	168	89	70	74	36	10
	275	101	55	58	61	37	2
	337	114	74	68	81	36	12
	334	117	75	62	80	33	11
	220	77	53	41	49	37	12
	429	154	98	85	92	27	3
MEAN	327.80	118.00	74.20	60.90	74.00	34.40	8.80
SD	59.92	25.58	13.96	13.38	15.21	3.09	4.32

CASE	MOE1	MOE1A	MOE1B	MOE1C	MOE1D	MOE3	MOE4
2	172	62	47	24	39	41	5
	148	44	34	23	47	43	6
	187	69	46	28	44	43	11
	137	45	24	25	43	42	12
	166	51	37	22	56	44	6
	142	49	26	21	46	42	12
	141	44	36	21	40	41	7
	176	58	51	24	43	41	8
	170	54	44	30	42	43	12
	162	60	41	33	38	41	6
MEAN	160.10	52.60	38.60	25.10	43.80	42.10	8.50
SD	17.08	8.53	8.92	4.01	5.16	1.10	2.92

Table 6. Summarized Output from Model.

CASE	MOE1	MOE1A	MOE1B	MOE1C	MOE1D	MOE3	MOE4
3	172	61	36	27	48	41	1
	145	47	28	28	42	43	10
	185	62	38	32	53	40	3
	152	43	29	36	44	39	11
	179	61	41	31	46	40	4
	187	71	33	34	49	40	4
	176	57	34	32	53	41	5
	182	68	36	24	54	39	11
	143	58	19	21	45	41	8
	169	66	26	30	47	40	3
MEAN	169.00	59.40	32.00	29.50	48.10	40.40	6.00
SD	16.49	8.78	6.53	4.58	4.12	1.17	3.68

CASE	MOE1	MOE1A	MOE1B	MOE1C	MOE1D	MOE3	MOE4
4	95	24	24	13	34	41	5
	92	15	20	18	39	43	2
	86	17	13	19	37	48	4
	100	22	16	21	41	41	9
	84	16	15	15	38	43	2
	109	26	21	25	37	41	2
	87	12	15	20	40	45	4
	101	15	25	26	35	41	3
	78	14	17	16	31	42	5
	96	23	27	18	28	44	7
MEAN	92.80	18.40	19.30	19.10	36.00	42.90	4.30
SD	9.27	4.88	4.83	4.12	4.08	2.28	2.31

CASE	MOE1	MOE1A	MOE1B	MOE1C	MOE1D	MOE3	MOE4
5	94	33	16	22	23	49	1
	104	23	11	33	37	46	6
	80	15	7	25	33	56	6
	106	30	22	19	35	46	6
	102	18	15	28	41	48	1
	102	16	23	18	45	50	5
	111	26	24	28	33	46	4
	117	33	12	34	38	52	5
	70	16	13	19	22	48	2
	100	24	27	17	32	46	3
MEAN	98.60	23.40	17.00	24.30	33.90	48.70	3.90
SD	14.09	7.03	6.60	6.25	7.20	3.27	2.02

Table 7. Summarized Output Continued.

APPENDIX D. STATISTICAL ANALYSIS TABLES

CASE	MOE1	MOE3	MOE4
1	0.950	0.166	0.26
2	0.789	0.103	0.30
3	0.337	0.132	0.28
4	0.500	0.310	0.53
5	0.108	0.301	0.29

Table 8. KS Test Results.

MOE1				
CASE	2	3	4	5
1	0.0000	0.0000	0.0000	0.0000
2		0.2510	0.0000	0.0000
3			0.0000	0.0000
4				0.2912
MOE3				
CASE	2	3	4	5
1	0.0000	0.0000	0.0000	0.0000
2		0.0030	0.3340	0.0000
3			0.0065	0.0000
4				0.0002
MOE4				
CASE	2	3	4	5
1	0.8570	0.1360	0.0094	0.0044
2		0.1096	0.0022	0.0007
3			0.2321	0.1314
4				0.6855

Table 9. T-test Results.

MOE1				
CASE	2	3	4	5
1	0.0000	0.0000	0.0000	0.0000
2		0.1731	0.0000	0.0002
3			0.0006	0.0002
4				0.1506
MOE3				
CASE	2	3	4	5
1	0.0002	0.0002	0.0002	0.0002
2		0.0050	0.5808	0.0020
3			0.0036	0.0020
4				0.0070
MOE4				
CASE	2	3	4	5
1	0.8178	0.1378	0.0299	0.0227
2		0.0624	0.0038	0.0016
3			0.3405	0.3409
4				0.9087

Table 10. Wilcoxon Test Results.

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   Code 037, Bldg. 234, HA-220
   699 Dyer Road
   Monterey, CA 93940

7. Project Manager....................1
   Unmanned Ground Vehicle/Systems Joint Project Office
   U.S. Army Aviation and Missile Command
   Redstone Arsenal, AL 35898-8060

8. Chairman Michael Morgan....................1
   Department of Mathematics, Code MA/Mw
   Naval Postgraduate School
   Monterey, CA 93943

9. Professor Bard K. Mansager......1
Department of Mathematics, Code MA/Ma
Naval Postgraduate School
Monterey, CA 93943

10. Professor Maurice D. Weir......1
Department of Mathematics, Code MA/Wc
Naval Postgraduate School
Monterey, CA 93943

11. Capt John F. America......2
1433 Admiral Drive
Woodbridge, VA 22192